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2014-2015 YEAR BOOK

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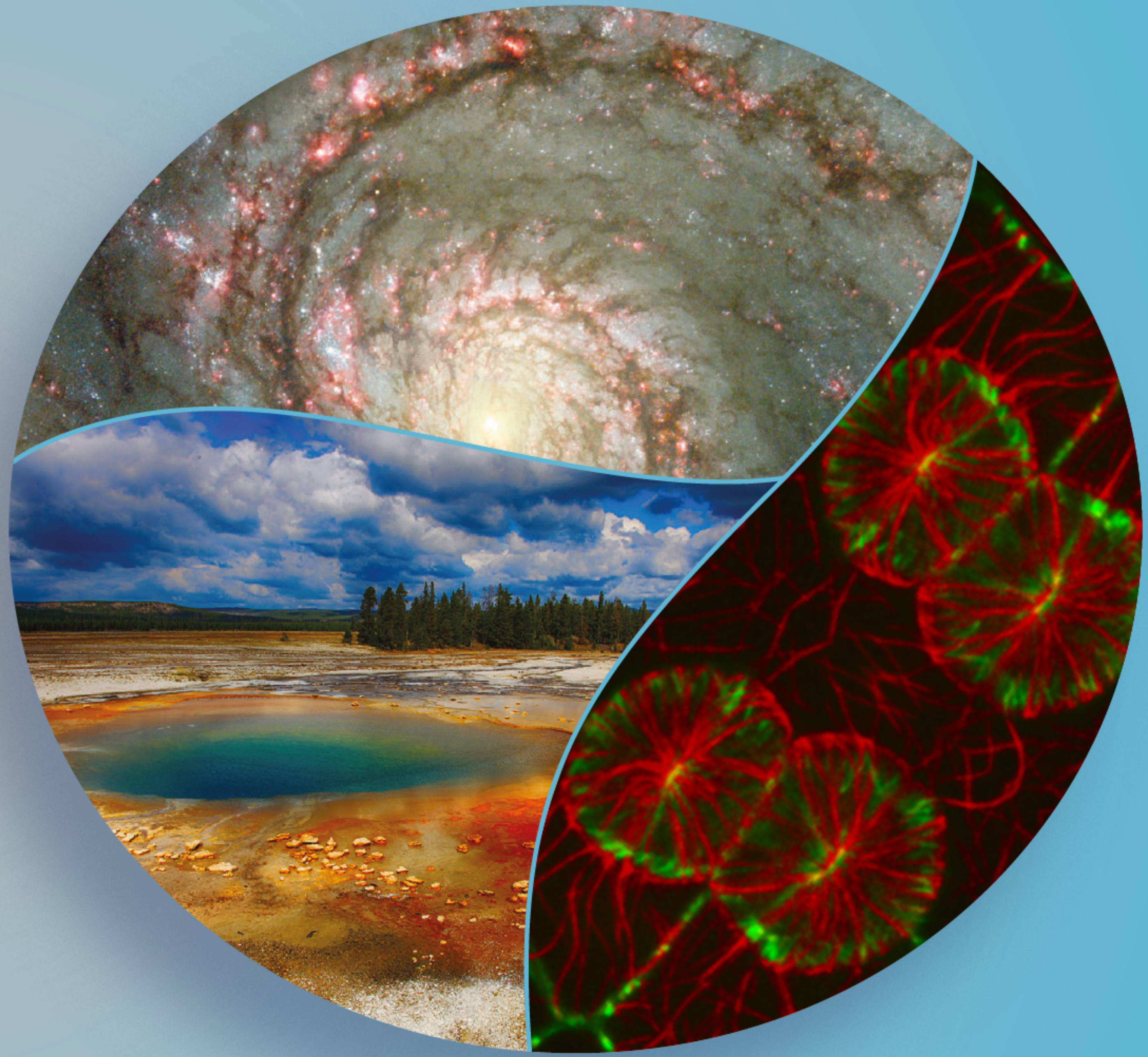

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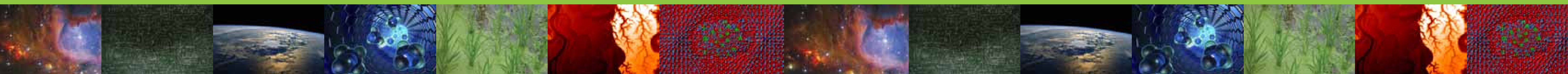

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2014-2015 YEAR BOOK

The President's Report

July 1, 2014 - June 30, 2015

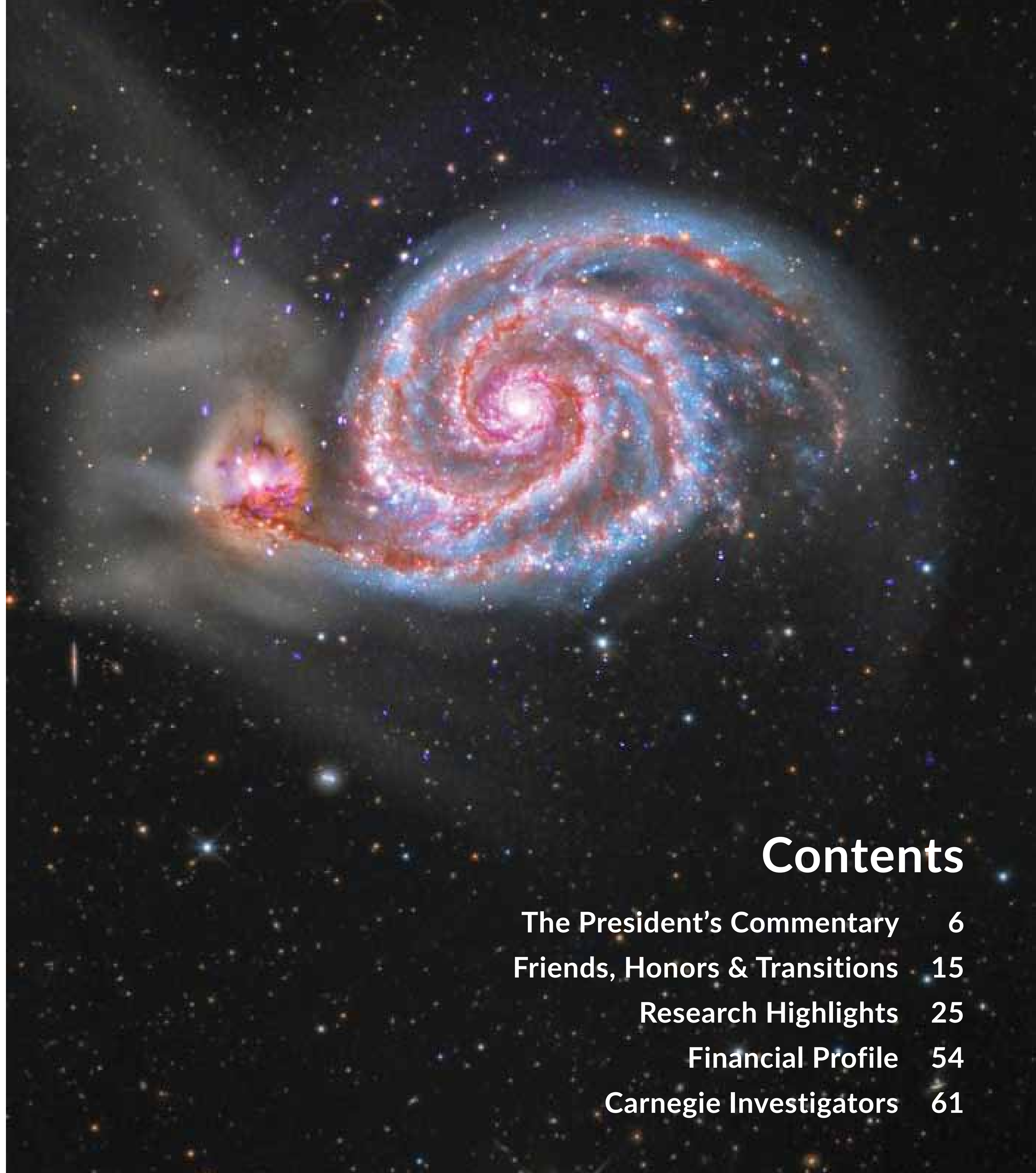
CARNEGIE INSTITUTION FOR SCIENCE

About Carnegie

". . . to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind . . ."

The Carnegie Institution was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At six research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

Carnegie Institution for Science

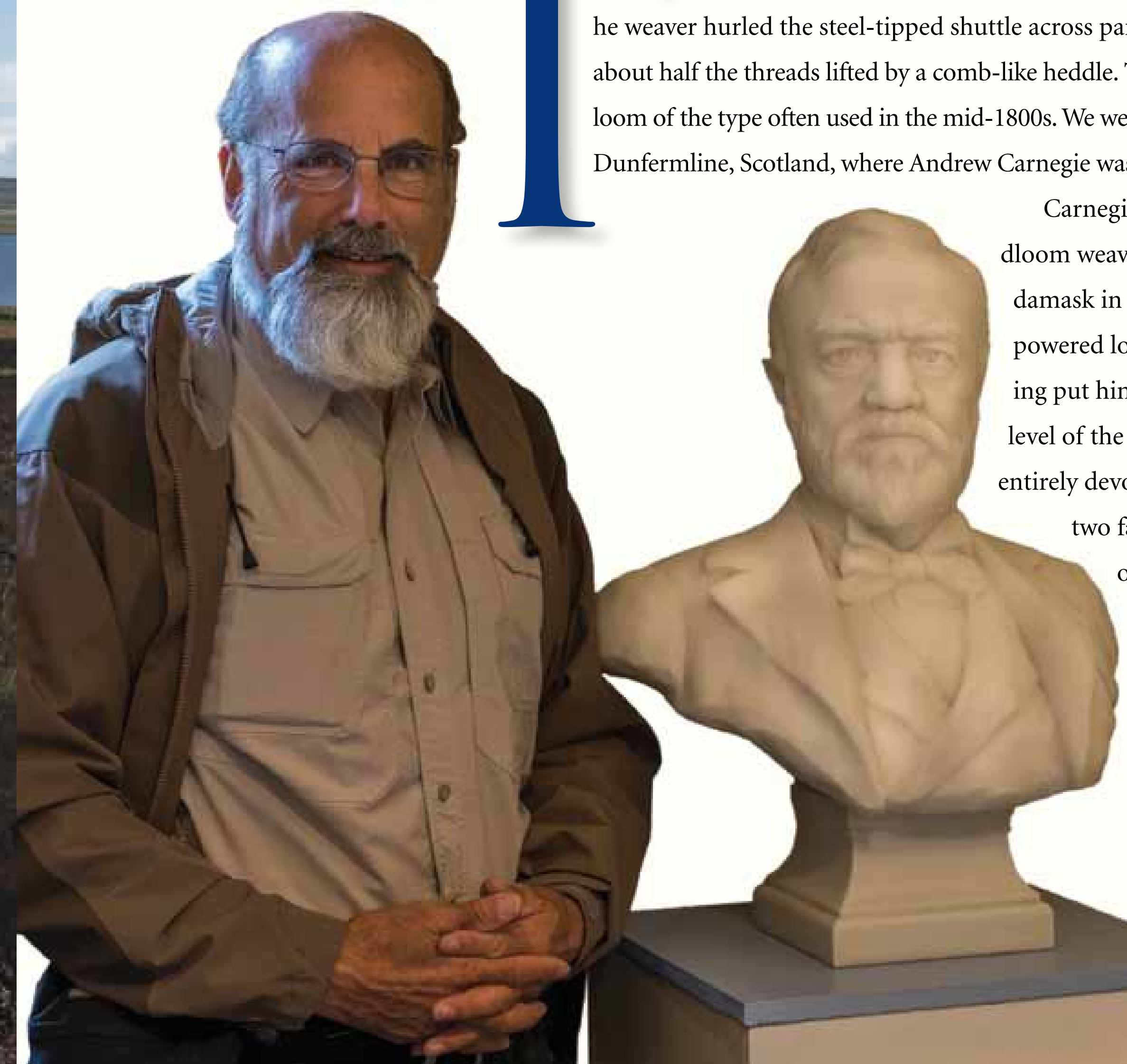


Contents

Weaving Together Carnegie Science

The weaver hurled the steel-tipped shuttle across parallel lines of warp threads, about half the threads lifted by a comb-like heddle. The loom was a Jacquard loom of the type often used in the mid-1800s. We were standing in a cottage in Dunfermline, Scotland, where Andrew Carnegie was born in 1835.

Carnegie's father William, a handloom weaver, spent years producing damask in this room before steam-powered looms and industrial weaving put him out of work. The street level of the Dunfermline cottage was entirely devoted to weaving. Upstairs two families lived, one in each of the two rooms. William's craft placed him among



The Ring of Brodgar (far left) is a neolithic (2500-200 BC) site in Orkney, Scotland, that is 104 meters in diameter. The purpose of the ring of stones is unknown.

Carnegie president Matthew Scott stands next to a bust of Andrew Carnegie in Dunfermline, Scotland.

Images courtesy Matthew Scott

Andrew Carnegie's Origins

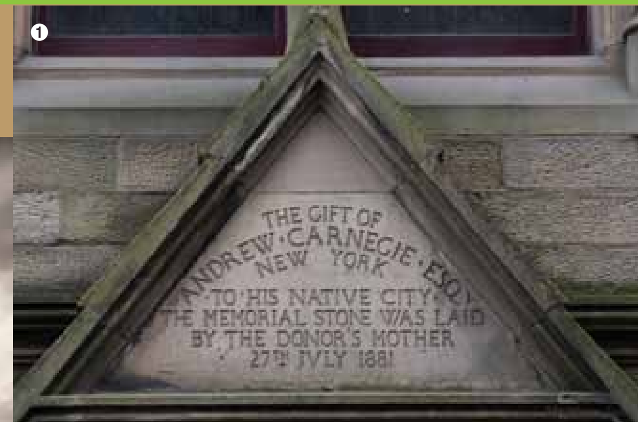
❶ Andrew Carnegie was born in this cottage in 1835. ❷ The bottom floor was reserved for weaving and housed a Jacquard loom. ❸ The Carnegie family lived in one upstairs room. ❹ ❺ ❻ Weaving intricate patterns is determined by the order in which heddles, the comb-like pieces that separate the threads, are raised and lowered. At the end of the 1700s, weavers used cards with punched holes to instruct the order in which heddles were raised or lowered. This technique was a precursor to computer punch cards.

the aristocracy of workers, but you would not know it from the space shared by the four members of the family. With 12-year-old Andrew, and the rest of the family, they sold everything to purchase tickets and soon embarked for America on the ship Wiscasset, a former whaler built in Maine.

In 1881, Andrew came back in gratitude to leave a lasting impact upon Dunfermline. The first of the more than 2,400 libraries he created around the world was built in Dunfermline; it stands a short distance from his cottage. Not far away, Dunfermline's spectacular church is graced with stained glass from the Carnegie family, and Carnegie Hall (not that one) hosts Celtic music and fine theater. The auditorium, like ours at P Street headquarters, has been under renovation.

Damask patterns are intricate, and weavers devised ways to simplify the process of creation: they used codes. On a loom, each heddle is threaded with a specific group of warp threads, for example—alternate threads, so that lifting different heddles or combinations of heddles will give rise to patterns; the shuttle carries the weft thread across the loom either above or below sets of warp threads. Complex patterns are created by the order in which heddles or sets of heddles raise and lower the warp threads. At the end of the 1700s, new technology automated loom programming, in a way similar to the way player pianos were later programmed: cards with punched holes served as a code for the individual warp threads in each row. A thread would be raised or stopped according to whether its guiding hook found a hole or solid material in the punch card above. Later the idea of using hole patterns in cards to carry such codes became the basis for computer punch cards that were used in the 1970s by computer programmers. Thus the technology used by William Carnegie connects directly to modern computer programming, but we use electronic ones and zeroes now instead of the presence or absence of a punched hole.

What would William or Andrew think if they could see the Carnegie high-performance computing (HPC) facility we have constructed at Stanford? This HPC



Giving Back

Andrew Carnegie's success allowed him to give back to Dunfermline.
❶ The first of the 2,400 Carnegie libraries was built there. ❷ He also donated stained glass to adorn the church and built ❸ Carnegie Hall, where performances are still held in the auditorium.

Images courtesy Matthew Scott

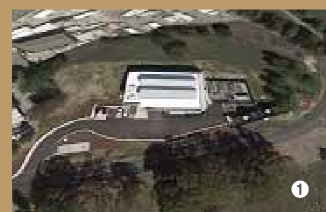
resource will serve members of all our Carnegie departments and will allow a speed and sophistication of computational science that is now required for many, perhaps most, of our scientific projects. For much of the past year a team composed of representatives from each Carnegie Science department has met to shape our future computational needs in light of specific projects that are in progress or on the horizon. They considered both hardware and software needs and what sorts of skilled staff will be needed to fully exploit the potential of the new facilities. From this effort emerged a dynamic plan, which we are putting into action now. Visualizing, analyzing, and modeling the origins of the universe; deciphering fluctuations of gene activities during development; measuring and modeling dynamic fluxes of tectonic and convective movements within the Earth; modeling the properties of never-before synthesized chemicals at high pressures; analyzing properties of families of proteins; assessing chemical and physical properties of developing planets; or testing properties of tens of thousands of mutant algal cells. All these and more require new approaches and very fast computing.

What makes these plans particularly important and exciting to me is the "organic" unification of our scientists that happened along the way. When was the last time plant biologists, astronomers, and geophysicists had a common language? Each had to explain to the others their goals, their kinds of scientific questions, their approaches, and what sort of computational staff and infrastructure would be needed to succeed. As these discussions continue they may well deepen into collaborations, where an analogy between analyses being done in these different fields turns into a method that serves widely different fields of science.

New High-Performance Computing Center

Scientific computing is fundamental to the missions of world-class research institutions. Carnegie embarked on a new high-performance computing (HPC) facility, located at Stanford University. It will serve members of all Carnegie departments. A team was formed from representatives from each department to define future computational needs. They focus on four main areas—scientific visualization, big data and data mining, scientific programming and algorithm developments, and education and outreach. The center will allow the speed and sophistication that computational science now requires for many of Carnegie's projects. ❶ ❷ The state-of-the art facility, shown from above and up close, is highly energy efficient. ❸ A passive cooling system resides on the roof. ❹ ❺ It has a diesel back-up generator and flywheels allow uninterrupted power. The facility can house 180 racks. ❻ ❼ ❽ There are nearly 100 racks already operational; among them are a Cray cluster, Stanford's Sherlock cluster, and Carnegie's Memex cluster.

Images courtesy Gotthard Sághi-Szabó








Visualization is a good example, the interpretation of complex patterns in space and time—woven textures of planets and galaxies, evolution of minerals and organisms in concert, fluctuating organelles in moving and dividing cells, seismic flows deep underground, chemical responses of forests to seasons and climate change and fires. Computers "see" patterns within patterns, absorbing and recognizing features not easily spotted by a human staring at a screen. Viewing scientific data in new and powerful ways allows scientists to understand better, a first step toward new hypotheses and experiments.

The beautiful patterns created by William Carnegie and his artistic peers reflect colors and textures of the Scottish countryside. In the same way, the elegance of scientific insights coming from observation, experimentation, deduction—and often computational analysis—reflect the wonderful community and rich textures of Carnegie Science. Equipped with new ideas and new tools, we look forward to another extraordinary year.

2014-2015 YEAR BOOK

Friends, Honors & Transitions

Carnegie Friends

Lifetime Giving Societies

The Carnegie Founders Society

Andrew Carnegie, the founder of the Carnegie Institution, established it with a gift of $10 million, ultimately giving a total of $22 million to the institution. His initial $10 million gift represents a special amount. Thus, individuals, including those who have directed contributions from private foundations and donor-advised funds, who support Carnegie with lifetime contributions of $10 million or more are recognized as members of the Carnegie Founders Society.

Caryl P. Haskins*
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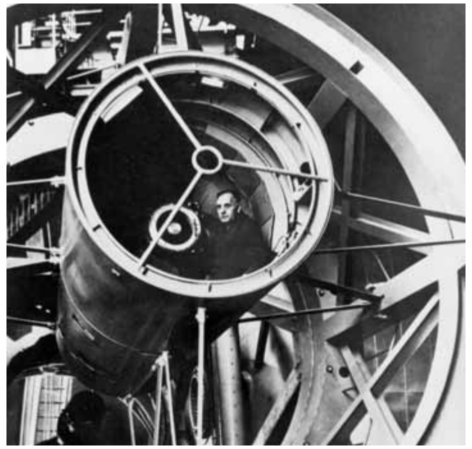
George P. Mitchell*



The Edwin Hubble Society

The most famous astronomer of the 20th century, Edwin Hubble, was a Carnegie astronomer. His observations that the universe is vastly larger than we thought, and that it is expanding, shattered our old concept of cosmology. Science often requires years of work before major discoveries like his can be made. The Edwin Hubble Society honors those whose lifetime contributions have helped the institution to foster such long-term, paradigm-changing research by recognizing those who have contributed between $1,000,000 and $9,999,999, as well as those individuals who have directed contributions to the Carnegie Institution at that level from private foundations and donor-advised funds.

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The Vannevar Bush Society

Vannevar Bush, the renowned leader of American scientific research of his time, served as Carnegie's president from 1939 to 1955. Bush believed in the power of private organizations and the conviction that it is good for man to know. The Vannevar Bush Society recognizes individuals who have made lifetime contributions of between $100,000 to $999,999, as well as those individuals who have directed contributions to the Carnegie Institution at that level from private foundations and donor-advised funds.

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The Second Century Legacy Society

The Carnegie Institution is now in its second century of supporting scientific research and discovery. The Second Century Legacy Society recognizes individuals who have remembered, or intend to remember, the Carnegie Institution in their estate plans and those who support the institution through other forms of planned giving.

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(Gifts Received Between July 1, 2014, and June 30, 2015)

The Barbara McClintock Society

An icon of Carnegie science, Barbara McClintock was a Carnegie plant biologist from 1943 until her retirement. She was a giant in the field of maize genetics and received the 1983 Nobel Prize in Physiology/Medicine for her work on patterns of genetic inheritance. She was the first woman to win an unshared Nobel Prize in this category. To sustain researchers like McClintock, annual contributions to the Carnegie Institution are essential. The McClintock Society thus recognizes generous individuals who contribute $10,000 or more in a fiscal year, as well as those individuals who have directed contributions to the Carnegie Institution at that level from private foundations and donor-advised funds.

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Anthony P. Mahowald
Steven R. Majewski
Thomas Malin
William G. and Phoebe Mallard
Bernard M. Malloy
Stephen P. Maran
Jerry Markowitz
Jenna Markowski
Janet E. Marott
Cindy Marsh
Barbara C. Martin
Elaine S. Marvel
John R. Mashey

John W. Maslin
Mario and Nancy Bennett Mateo
John Matthews
James Mattingly
James M. and Roxane Mattinson
David A. Mauriello
William Maxwell
Peter J. Maynard
Peter J. McAniff
Jennifer McCabe
Robert H. and
Dorothy A. McCallister
James A. McDermott
Don H. McDowell
Darren McElfresh
Rhonda McNulty
Thomas A. Mehlhorn
D. Joel and Mary Mellema
Robert Mendelson
T. Spencer Metcalf
Marissa Meyer
Richard Meyer
Dennis F. Miller
Lee J. Miller
Michael B. Miller
Kimberly G. Mitchell
Joseph F. Moore
Michael B. Moran
Christopher Morgan
James Morgan
Marilyn E. Morgan
Mary Lee Morrison and
William B. Upholt
John M. Morrow
John W. Mothersole
Gary G. Mrenak
David Murad
Seanan Murphy
Charles G. Myers
Ralph H. Nafziger
Cara Nakoneczny
Nentcho Nentchev
Jon Neumann
Trevor L. Neve
Phillip and Sonia Newmark
Donald S. Nicholson
Richard L. Nielsen
John Ray Nooncaster
Michael B. O'Connor
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Raymond and Bette Ann Page
Michael S. Paisner
Maria Papachatzi
Dr. and Mrs. R. Bryce Parry
Pratik Patel
Rajan Patel
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Patsy M. Perlman
Katherine Perry
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Sarah Polow
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Yvonne Ricard
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R. Michael Rich
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Herman H. Rieke
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Cristina Roark
John D. Roberts
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Peter and Doris Roitman
Nancy G. Roman
Milton M. and Ingrid R. Rose
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Teresa Wilkerson
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Eugene and Alicia Scott
Malcolm G. Scully
Michael Seibert
Frederic T. Selleck
Roberta Shaffer
Robert D. and Claire C. Shaver
Thomas F. Sheehan
Nobumichi Shimizu
Alisha Shudy
Shaukat M. Siddiqi
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David E. Snead
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Samantha Nolan
Frank Spokane
Ken and Jean Stadel
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Diane Stanley
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Kathleen Taimi
Gary R. Tanigawa
Colin Taylor
David Taylor
Laura Taylor
Mack Taylor
Dilaun Terry
Dara Tesse
Leslie Thompson
Michael Tobias
Susan B. Tobias
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Martin Trees
Lynette Trygstad
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Evan Tunis
Nickolos Valdez
Lee Van Duzer
W. Karl Van Newkirk
Robert S. Vance, Jr.
Larry N. Vanderhoef
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Arthur H. Vaughan*
Vincent Vella
Nicole Ventrone
Vikram Venu
Laura L. Viehmyer
Katharine Villard
Michelle Vincent
Thomas A. Waddell
Mallory and Diana Walker
Richard J. Walker and
Mary F. Horan

Douglas J. Wallis
Wayne H. Warren, Jr.
Mark Waterman
Richard Wattis
Skyler Weaver
Johannes Weertman
Marcus Weller
Philip A. and Barbara A. Wenger
Lorrie D. Westerlund
Edward White V
William M. White
Marsha Lynn Wilkins
James E. Williams
Matthew Williamson
Stewart Wills
Thomas Wilson
Jeremy Winter
Matthew Winter
Cecily J. Wolfe
Eric and Sandra Wolman
Laquita Wood
Lois R. Wood
Sean Woodall
Margaret D. Woodring
Mary Jo Woods
Robert J. Yamartino
Pamela D. Yerkes
Richard Young and Bonnie Beamer
Robert A. Young
Leon Zar
Robert A. Zarzar
Kelly Zehnder
William Zhang
Timothy A. Zimmerlin
Scott Zogg
Douglas Zwiener

*Deceased

Members were qualified with records we believe to be accurate. If there are any questions, please call Irene Stirling at 202.939.1122.

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$1,000,000 or more
W.M. Keck Foundation
The Cynthia and George Mitchell Foundation
The San Simeon Fund, Inc.
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Honors & Transitions

Honors

Embryology

Marnie Halpern was named a Fellow of the American Association for the Advancement of Science. Junior Investigator **Zhao Zhang** received the prestigious Larry Sandler Memorial Award of the Genetics Society of America. The annual award is given for the best research that led to a Ph.D. using the fruit fly *Drosophila.*

Geophysical Laboratory

Anat Shahar was awarded the Clarke Award of the Geochemical Society. It is awarded to an early-career scientist for "a single outstanding contribution to geochemistry or cosmochemistry, published either as a single paper or a series of papers on a single topic."

Global Ecology

Chris Field, director of Global Ecology, was awarded the fifth annual Stephen H. Schneider Award for Outstanding Climate Science Communication by Climate One. The American Geophysical Union (AGU) bestowed him with the 2014 Roger Revelle Medal. **Joseph A. Berry** was elected to the National Academy of Sciences. **Greg Asner** was elected a Fellow of the American Geophysical Union (AGU).

Observatories

Carnegie astronomer **Mark Phillips**, interim director of the Las Campanas Observatory, is one of a group of scientists honored with the Breakthrough Prize in Fundamental Physics.

Plant Biology

Director **Wolf Frommer** was elected a member of the German Academy of Sciences, Leopoldina, one of the world's oldest national academies. **Zhiyong Wang** received the Humboldt Research Award, one of Germany's most-prestigious prizes. **David Ehrhardt** was awarded an honorary fellowship of the Royal Microscopical Society.

Terrestrial Magnetism

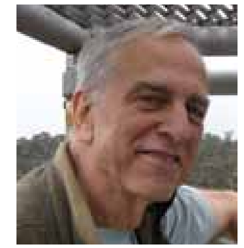
Sean Solomon, director of Carnegie's Department of Terrestrial Magnetism from 1992 until 2012, received the nation's highest scientific award, the National Medal of Science. **Erik Hauri** was made a fellow of both the Geochemical Society and European Association of Geochemistry.


★ *Marnie Halpern*


★ *Zhao Zhang*


★ *Anat Shahar*


★ *Chris Field*


★ *Joseph A. Berry*

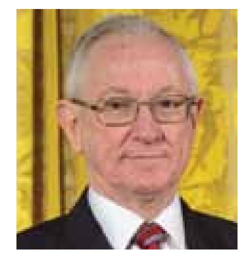

★ *Greg Asner*


★ *Mark Phillips*


★ *Wolf Frommer*

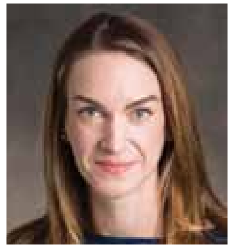

★ *Zhiyong Wang*


★ *David Ehrhardt*


★ *Sean Solomon*


★ *Erik Hauri*


★*Timothy Doyle*


★*Margaret Moerchen*


★*John Mulchaey*


★*Rick Carlson*

Transitions

Administration

Timothy Doyle joined Carnegie as Chief Operating Officer. He was Associate Dean for Finance and CFO for Harvard's School of Engineering and Applied Sciences (SEAS). Doyle has a unique blend of experience including complex administrative and financial organizations, private sector businesses, and most recently the research and education sectors. His diverse financial and operations background spans the areas of strategic leadership, financial systems and controls, budgeting and planning, and administration efficiency.

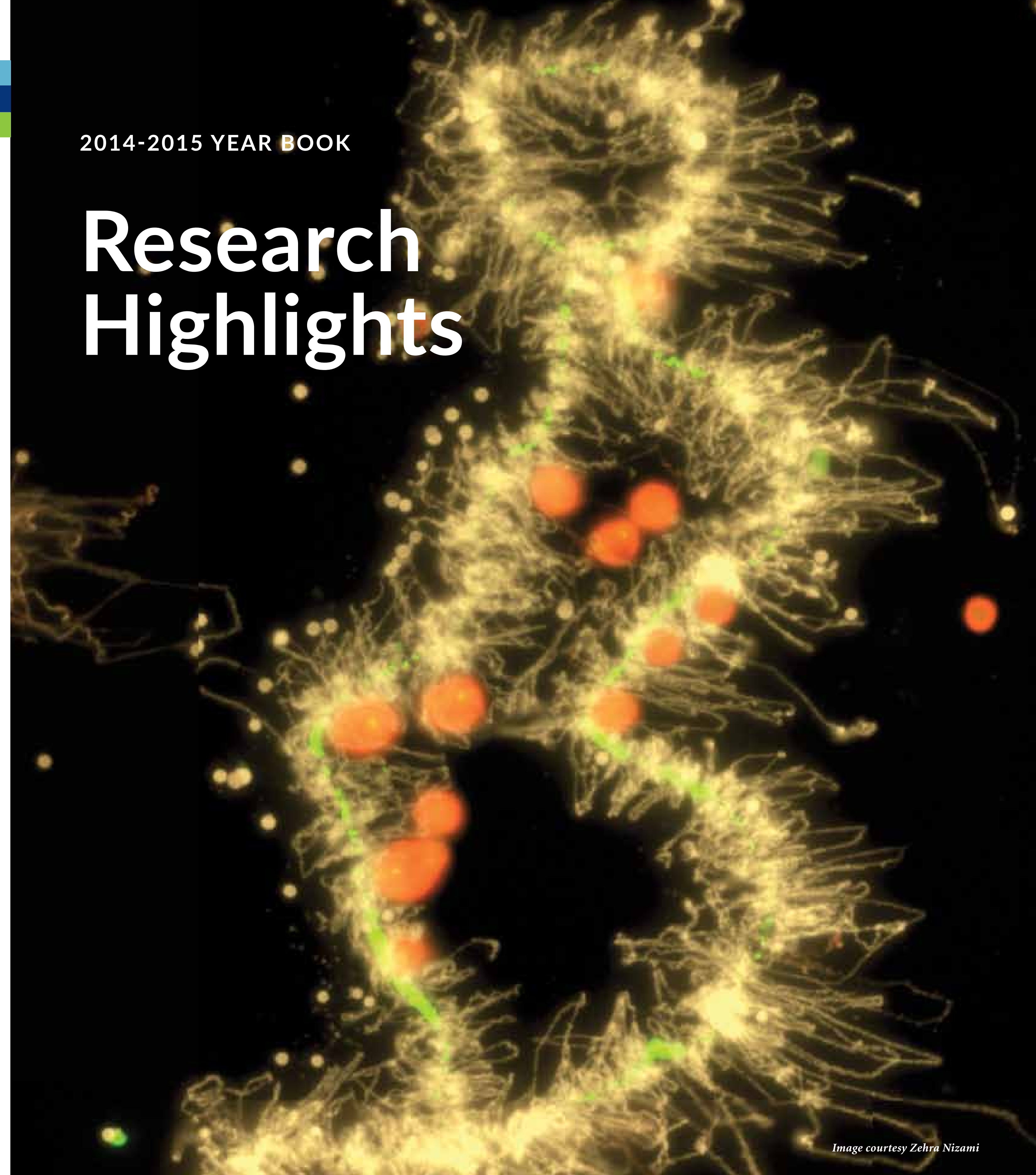
Margaret Moerchen was appointed Science Deputy to the President. She is an astronomer and was associate editor of *Science* magazine where she handled all astronomy and planetary science manuscripts. Her interactions at the journal enhanced her knowledge of other physical sciences including geophysics, climate science, chemistry, materials science, and physics. Previously, she worked on instrument-building teams at the world's largest telescopes, collaborating with diverse scientists and engineers.

Observatories

John Mulchaey was appointed the Crawford H. Greenewalt Director of the Carnegie Observatories. Mulchaey has been at Carnegie for 20 years. He investigates groups and clusters of galaxies, elliptical galaxies, dark matter—the invisible material that makes up most of the universe—active galaxies, and black holes. Although Mulchaey works extensively with space-based, X-ray telescopes, the optical telescopes at Carnegie's Las Campanas Observatory play a central role in his research for follow-up observations, which are necessary to determine galaxy type and distance.

Terrestrial Magnetism

Richard Carlson was appointed director of Terrestrial Magnetism. He has been with Carnegie since 1980, originally as a postdoctoral fellow. Carlson studies the chemical and physical processes that formed the terrestrial planets. Using the known decay rates of various radioactive isotopes, he investigates the chronology of early processes on small planetary objects and studies the chemical and physical aspects of old and young crust-forming processes on Earth. He also studies nucleosynthetic differences in the early solar nebula.



2014-2015 YEAR BOOK

Research Highlights

Image courtesy Zehra Nizami

Astronomy

Investigating the Birth, Structure, and Fate of the Universe

Small Galaxies, Big Impact

Nonastronomers might assume that the universe's tiniest galaxies do not matter much on a cosmic scale. But the Observatories' Josh Simon spends much of his time demonstrating that we can learn a great deal from the smallest galaxies.

Dwarf galaxies often orbit larger systems like our Milky Way, at distances between 75,000 and more than 1 million light years. Simon's research ranges from "garden-variety" dwarf galaxies, containing millions of stars, to the recently identified "ultra-faint" dwarf galaxies, with only a few thousand stars. Most of the Milky Way's larger dwarf satellites, such as the Sculptor dwarf spheroidal galaxy, were discovered decades ago by former Carnegie astronomers Harlow Shapley, Albert Wilson, and Robert Harrington. But ultra-faint dwarfs came to light only in 2005 with the advent of deep digital sky surveys.

By measuring stellar motions within the ultra-faint dwarfs, Simon and colleagues showed that they are surprisingly heavy. These galaxies weigh nearly as much as ordinary dwarfs despite hosting many fewer stars. Simon's measurements demonstrated that ultra-faint dwarfs are made almost entirely of dark matter—the invisible matter that makes up most of the universe. Less than 1% of their mass consists of ordinary matter like protons, neutrons, and electrons, and 99% to 99.97% of their mass is dark matter. As a result, these smallest dwarfs have become the center of attention for particle physicists and astronomers studying dark matter.

The whopping dark matter content
is not the only surprise.

Among many other areas of research, Carnegie's Josh Simon studies ultra-faint dwarf galaxies.

The whopping dark matter content is not the only surprise. Simon, Anna Frebel of MIT, and their collaborators unexpectedly found that the abundance of elements like magnesium, calcium, and titanium in ultra-faint dwarf galaxy stars is almost identical to the abundance of those elements in similarly old Milky Way stars. Heavier elements such as barium and strontium, however, are much rarer in the dwarf galaxies; their absence may provide a clue as to how such elements are created by supernova explosions.

Most of the Milky Way's larger dwarf satellites, such as the Sculptor dwarf spheroidal galaxy shown here, were discovered long ago by former Carnegie astronomers Harlow Shapley, Albert Wilson, and Robert Harrington. However, ultra-faint dwarfs, which Josh Simon studies, came to attention with the deep digital sky surveys in the mid 2000s.

Image courtesy European Southern Observatory

The latest development has been the discovery of many previously undetected dwarfs near the Milky Way by the Dark Energy Survey, among other efforts. Remarkably, a total of 23 dwarf galaxy candidates have been identified in just three months this spring, compared to only 26 Milky Way satellites known prior to 2015. Most of the new discoveries are deep in the southern skies, perfectly positioned for observations with the Magellan telescopes at Carnegie's Las Campanas Observatory in Chile. Simon expects that this cornucopia will keep him—and Magellan—busy for years to come.

The above right panel shows a Dark Energy Survey image of the sky, where the dwarf galaxy Reticulum II is nearly invisible. In the right panel all of the stars that do not belong to Reticulum II have been digitally removed so that the presence of the galaxy is actually apparent.

Image courtesy Fermilab/Dark Energy Survey

Astronomy

Continued

Relighting the Universe

The universe cooled furiously after the Big Bang, 13.7 billion years ago. Atoms assembled some 400,000 years later, with cooler temperatures allowing protons to join with electrons, forming hydrogen and clearing the murky gas. After about 500 million years the first galaxies began to form. Astronomers think that the intense energy of galactic star formation unbound the electrons in the hydrogen gas, in a period of "reionization" lasting from 500 million to 1,000 million years.

Alan Dressler looked for the faintest of these early galaxies to learn if they are abundant and energetic enough to drive reionization. Through a novel method, he was able to find galaxies five times fainter than before and reveal 25 times as many galaxies, enough to supply 25-50% of the ultraviolet light needed to reionize the universe: they are likely reionizing agents.

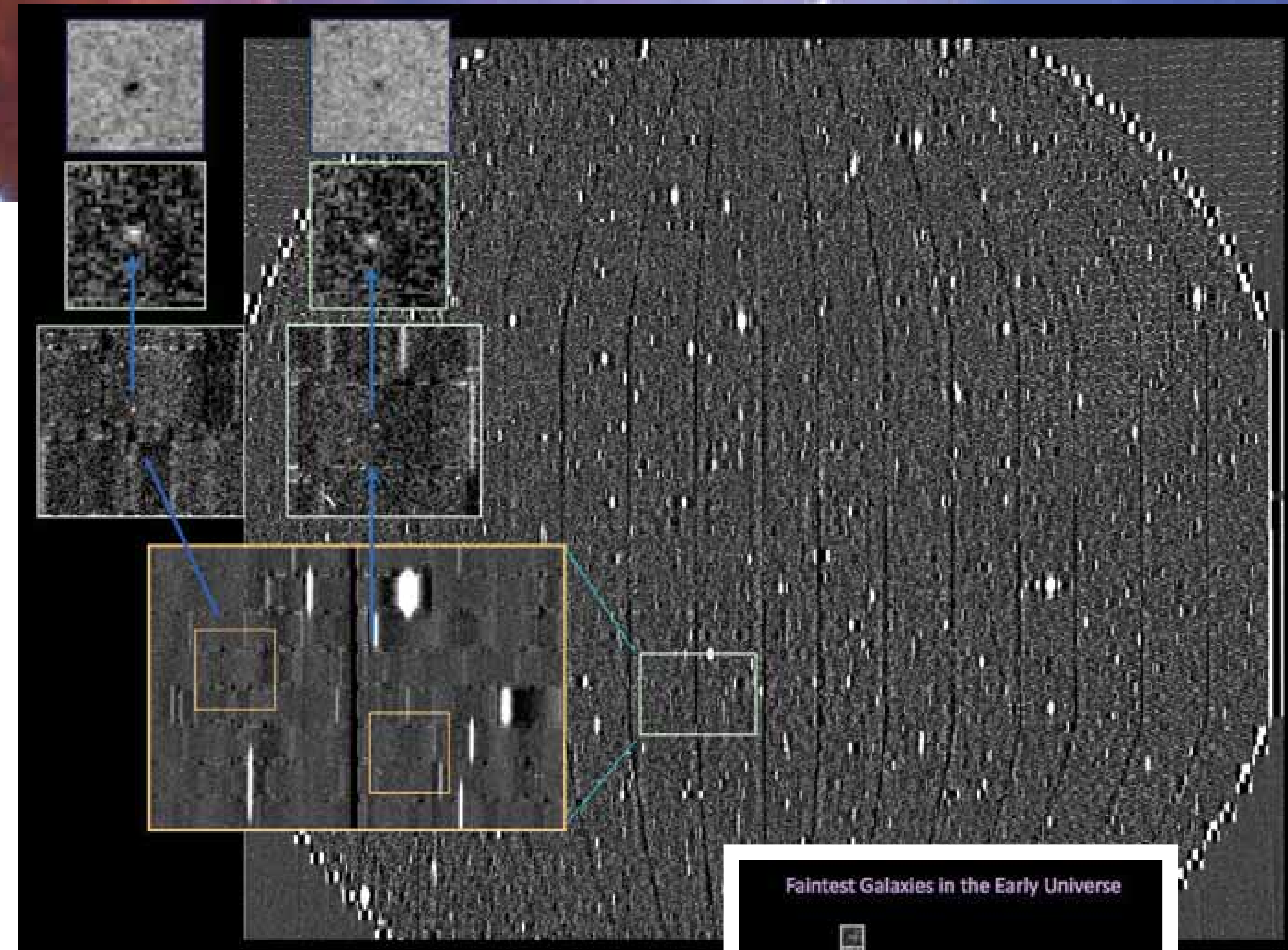
Telescopes witness the distant and young universe in real time. It is hard because the first galaxies were small and their starlight is feeble. Hubble Space Telescope images, however, reveal a sample of thousands of galaxies from the reionization epoch, but the total ultraviolet light from star formation in them is only about 10% of the amount needed.

The speculation has been that galaxies fainter than those found by Hubble supplied most of the energy for reionization. However, the deep imaging technique used could not find fainter galaxies. Dressler pushed fainter via a method developed by collaborators Crystal Martin (UC-Santa Barbara) and Marcin Sawicki (St. Mary's) that uses spectroscopy, the analysis of the light's spectrum, over the narrow band of imaging. With the Inamori-Magellan Areal Camera and Spectrograph (IMACS) on Magellan at Carnegie's Las Campanas Observatory, Dressler conducted a blind search covering 10% of the field of view by restricting the incoming wavelength to 150 angstroms of the 1500 angstroms typically observed. (An angstrom is a unit of length equal to one ten-billionth of a meter.) The light passing through each of 100 parallel "long slits" was dispersed to search for so-called Lyman-alpha emission lines, the signature light produced by gas glowing from star formation. Dressler looked for galaxies at the end of the reionization epoch.

The numbers of detected emission lines rises steeply with decreasing brightness. Weeding out foreground galaxies by taking additional deep spectra of 60 representative targets confirmed that 1/3 of the faint sources are early-universe galaxies—a dramatic rise in the number of faint, early-universe galaxies, enough to reionize the universe.

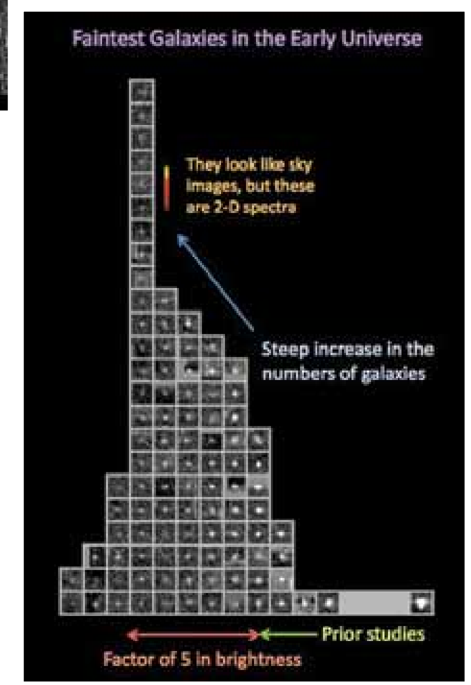
Carnegie's Alan Dressler

Image courtesy Tim Neighbors



The IMACS spectrograph imaged 100 parallel slices of the sky in the 150-angstroms wavelength band to build up a search area. This exposure required twenty hours of shutter-open time in excellent Las Campanas conditions over four nights. Short, bright vertical lines are the spectra of ordinary Milky Way stars whose light happens to pass through a slit. The figure shows the full IMACS field, with a small area enlarged several times to show two examples of the signature Lyman-alpha emission from galaxies at the end of the reionization epoch. The two top-left images are "negatives" that show the emission lines more clearly.

Image courtesy Alan Dressler

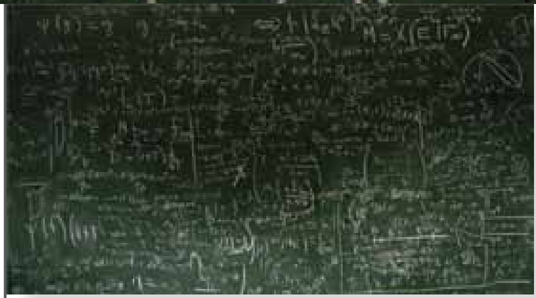


Each square shows 5 arcseconds of sky, a measurement that describes the apparent size of an object, and 25 angstroms of spectra with an emission line coming from star-forming gas in a galaxy. The new observations reach five times fainter objects than the prior imaging studies, and show a steep rise in the total number of detected sources. The 1/3 fraction of galaxies that are the signature Lyman-alpha emitters produce 25%-50% of the high-energy photons needed to reionize the universe.

Image courtesy Alan Dressler

The Carnegie Academy for Science Education & Math for America

Teaching the Art of Teaching Science and Math



STEM Gets Stronger

In October 2014, the Carnegie Academy for Science Education (CASE) joined forces with the District of Columbia Office of the State Superintendent of Education (OSSE) to launch the DC STEM Network. (STEM is Science, Technology, Engineering and Math.) This network is uniting community partners to design, guide, and advocate for improving STEM learning opportunities for Washington, D.C., students. The D.C. network joins initiatives in 22 states as part of a nationwide network led by the Battelle Memorial Institute. An advisory council of community leaders and a leadership team govern the network; CASE and OSSE staff provide backbone support. With over 20 years in D.C. teaching students and teachers about STEM, CASE is ideal to lead the program.

In March, CASE hosted a launch event, engaging 120 educators, industry partners, and community leaders in student-led lab experiments and interactive workshops that created seven working groups to increase access to STEM learning. The working groups cover mentoring and tutoring, in-school education, out-of-school educational opportunities, professional development for teachers, and community outreach. The network is connecting schools, industry partners, institutions of higher education, and STEM professionals to improve STEM programs and create opportunities for training and job experiences. Each working group developed and implemented an action plan. Outcomes from each of the working groups' activities were reported on at a DC STEM Summit in November 2015.

In July, CASE and OSSE trained 11 D.C. classroom teachers to become STEM ambassadors in the city to increase community engagement with the education efforts of the network. In August, Carnegie cohosted the STEM Leadership Academy with the Center for Inspired Teaching and OSSE. Thirty-four D.C. principals attended the two-day event to learn about the implementation of the Next Generation Science Standards and the Common Core State Standards for Mathematics, as well as interdisciplinary instruction. The standards are based on a framework developed by the National Research Council rendered by educators in 48 states. The goal is to teach science in a manner that mirrors the way science and engineering professionals approach their everyday work and to stress critical thinking and communication skills.

Katia Grigoriants (left) is the manager of Carnegie Academy for Science Education (CASE) strategic partnerships and development. Marlena Jones (middle) is the manager of CASE programs and outreach. Julie Edmonds (right) is the director of CASE and the DC STEM Network.

Image courtesy Blonde Photography

The March launch of the DC STEM Network, led by CASE at Carnegie's Washington, D.C., headquarters, witnessed some role reversal: students led the adult participants through the hands-on experiment of extracting DNA from strawberries.

Image courtesy Blonde Photography

The Carnegie Academy for Science Education & Math for America

Continued

Master Teacher Program Expands

National Math for America (M*f*A) is excited to announce the expansion of the Master Teacher Program, with the goal to establish a model for a corps of national master teachers in mathematics and science. This approach follows a recommendation from the 2010 President's Council of Advisors on Science and Technology (PCAST) report urging the formation of a nationwide STEM Master Teacher Corps. M*f*A also seeks to make teaching a respected career choice for the best minds in science and mathematics.

To qualify for the M*f*A DC Master Teacher Program, candidates need a strong math background, must have taught math for at least four years, and must have demonstrated leadership qualities. The rigorous selection process includes a complex application, PRAXIS exams, and an interview with a selection panel. If selected, the master teachers commit to teaching five years in the Washington, D.C., public schools. M*f*A DC Master Teachers receive a $10,000 salary supplement to reward their teaching excellence and encourage retention. They also receive a one-time grant to further their education, attend professional math meetings, or work toward National Board certification.

Over four years, M*f*A DC teachers could potentially teach some 32,000 D.C. students.

The M*f*A DC Master Teacher program started in 2011 and now includes nine Master Teachers from among those currently teaching mathematics in D.C. public or public charter schools. Three are alumni of the first cohorts of fellows, one is the 2011 Presidential Awardee for Excellence in Mathematics and Science Teaching, and another is the 2014 D.C. Teacher of the Year.

As part of the expansion, M*f*A DC hopes to recruit five Master Teachers per year over the next five years. In 2015, eight teachers applied and four were selected. Currently, there are 33 M*f*A DC teachers in the pipeline. These highly effective teachers strive to provide outstanding mathematics instruction; they impacted approximately 8,000 D.C. students in the public secondary schools last year. Over four years M*f*A DC teachers could potentially teach some 32,000 D.C. students.

M*f*A DC is directed by Bianca Abrams. Assistant director Paul Penniman was hired in 2015 to lead the expansion and its professional development. He has taught mathematics since 1978. He is the founder and executive director for Resources to Inspire Students and Educators (RISE), a nonprofit that has provided tutoring and mentoring to low-income D.C. youth, primarily in Wards 7 and 8, for the past 12 years.

Bianca Abrams has been the director of Math for America (M*f*A) DC since its inception in 2008.

Paul Penniman was hired in 2015 to lead the M*f*A DC expansion effort and professional development.

The Master Teacher Program regularly holds professional development sessions for the teachers.

Images courtesy Bianca Abrams

Earth/Planetary Science

Understanding the Formation and Evolution of the Planets and Their Place in the Cosmos

The Mystery of Deep Water Cycling

Lara Wagner uses seismic imaging to unravel the mysteries of Earth's deep water cycle. Deep water cycling mostly occurs in subduction zones: plate boundaries where one tectonic plate slides under another. At subduction zones, old oceanic crust is returned to the hot mantle, new continental crust is made, volcanoes and earthquakes form, and water enters and exits Earth's interior. Water, in turn, may play a key role in explaining why—among the rocky, terrestrial planets—only Earth has plate tectonics. Wagner believes that observing certain minerals' dehydration processes will help establish the steps in this water cycle. However, in most subduction zones, these steps almost all happen at nearly the same time and place, when the plate reaches the hot mantle and heats rapidly. This makes it difficult to tease them apart, or to know if any water is left behind in the sinking plate.

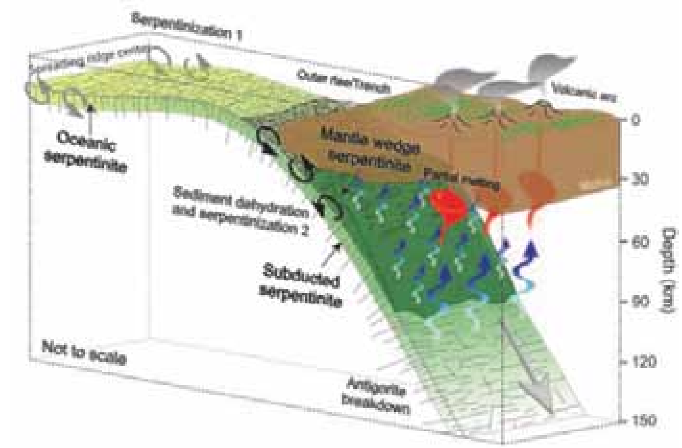
Wagner studies areas with "flat-slab subduction," in Peru, Chile, and Colombia, where heating occurs much more gradually because contact with hot mantle is delayed. This gradual heating allows Wagner to analyze the sequential breakdown of water-laden minerals that formed when the oceanic plate was still under water. By studying flat-slab subduction, Wagner can study both the fate of the water that is progressively released at shallower depths and the water that remains in the downgoing plate to be transported deep into the Earth.

To study the fate of water in subduction zones, Wagner has been deploying broadband seismometers for over 15 years in Chile and Peru to produce high-resolution images of seismic velocities in the Earth's interior. Seismic velocities are very sensitive to the presence of water. Wagner expected to see evidence of this progressively released water in the continental plate directly above the subducted oceanic plate.

Wagner found evidence for water, but she also found evidence that this water changes the composition of the upper plate by adding silica from subducted sediments. The continental crust has, on average, substantially higher silica concentrations than does oceanic crust. This high silica concentration has long been thought to be related to the formation of continents in subduction zones, but the precise mechanism remains a mystery. Wagner's work on the fate of subducted water continues, and her team is investigating ways to use smaller, lighter equipment to improve her ability to "see" water and its effects, deep in the Earth's interior.

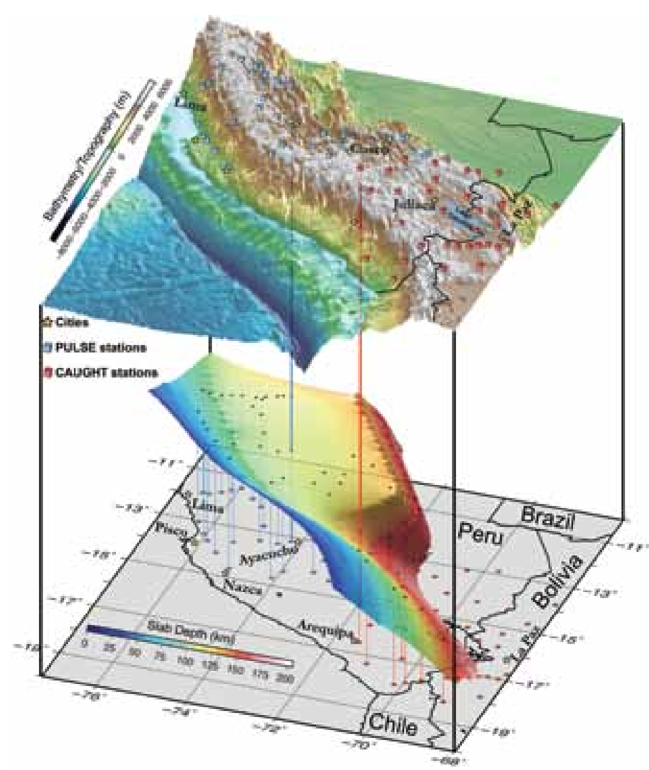
Installing seismic stations in remote field locations is time consuming and labor intensive. Lara Wagner (right) checks the data quality at one station in Peru. The team hopes to deploy smaller, lighter, seismic-sensing devices in the future.

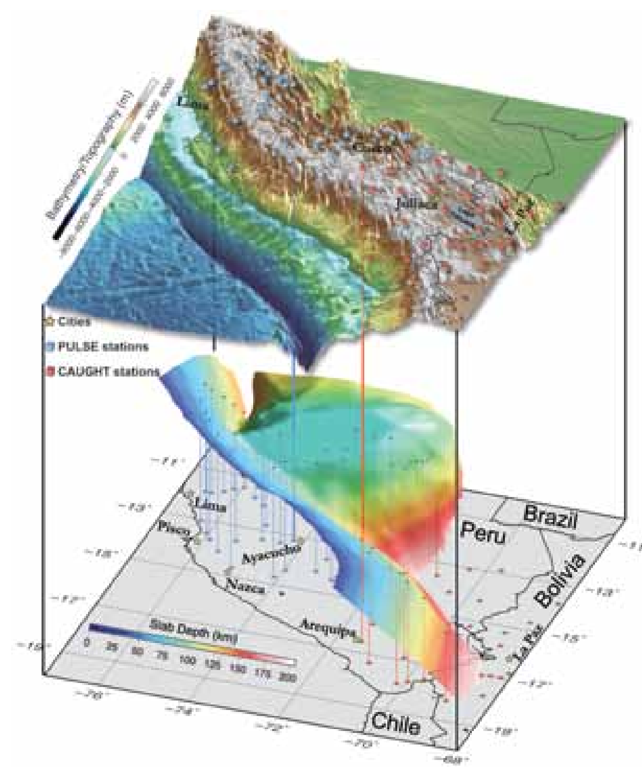
Image courtesy Lara Wagner



The Earth's interior has a layered structure. Places where tectonic plates slide under another (top left, in green), subduction zones, are the conduits for cycling old oceanic crust and water to the hot mantle. The sliding instigates major earthquakes, and the water released by subduction triggers the volcanism that characterizes subduction zones.

Image courtesy doi: 10.1130/2007.2421(08), GSA Special Papers 2007, v. 421, pp. 115-156





Both images (right) were rendered by Lara Wagner. The left image of a flat-slab subduction zone in Peru is from 1992 and was constructed using all available data at the time, most of which came from stations outside of South America. The one on the right, with much higher resolution, shows the tear on the northern portion of the flat slab where normal steep-dip subduction has reinitiated. The image is based on a model from Wagner's graduate student Knezevic Antonijevic. The more detailed image is based on data from 90 seismic stations that the team installed across Peru and Bolivia from 2010 to 2013. The local stations are key to "see" the structures below.

Images courtesy Lara Wagner

Earth/Planetary Science
Continued

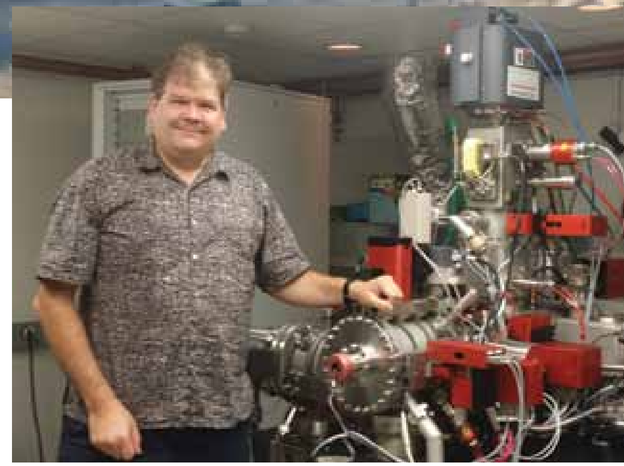
Mercury Isn't What We Thought

The MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission to Mercury team, including Deputy Principal Investigator Larry R. Nittler, has shattered what we thought we knew about the innermost planet, including its chemical composition and history. Surface chemistry maps recently revealed previously unidentified geochemical terranes—large regions with compositions distinct from the surrounding area.

Early in the mission, MESSENGER showed that Mercury's crust was shaped by ancient volcanic magmas derived from the partial melting of the mantle. The team also found that the planet has an unusual sulfur-rich and iron-poor composition, indicating that it formed from a different mix of materials than the other terrestrial planets. The new maps reveal remarkable chemical diversity and are critical to understanding the processes that shaped Mercury's mantle and crust.

...it formed from a different mix of materials than the other terrestrial planets.

The MESSENGER spacecraft was launched on August 3, 2004, and entered orbit on March 18, 2011, for a year-long study. After operating for three years longer than planned, MESSENGER ended its mission April 30, 2015, far surpassing goals. The little workhorse returned more than 250,000 images, ten times the planned number.



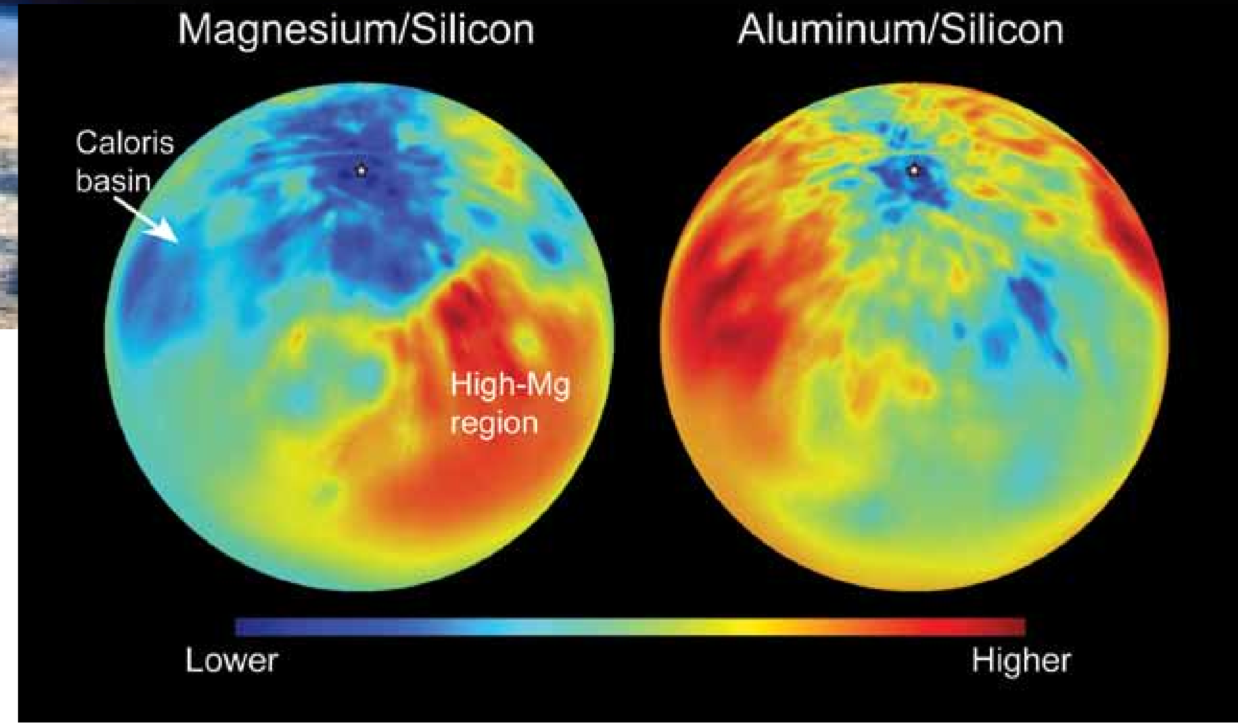
Larry Nittler, Deputy Principal Investigator of the MESSENGER Mission to Mercury, is in the Terrestrial Magnetism NanoSIMS lab.

Image courtesy Larry Nittler

Data from the spacecraft's X-Ray Spectrometer (XRS) and Gamma-Ray and Neutron Spectrometer (GRNS) provided concentrations of potassium, thorium, uranium, sodium, chlorine, and silicon, as well as ratios relative to silicon of the important rock-forming elements magnesium, aluminum, sulfur, calcium, and iron. Until recently, geochemical maps for some of these elements and ratios were limited to one hemisphere with poor resolution. Nittler, former postdoc Shoshana Weider, and team used a novel method to produce global maps of the magnesium to silicon and aluminum to silicon abundance ratios via a technique by which X-rays emitted from the Sun's atmosphere al-lowed them to examine the planet's surface composition. The global magnesium and aluminum maps were paired with less spatially complete maps of the ratios of sulfur, calcium and iron to silicon, and other data sets.

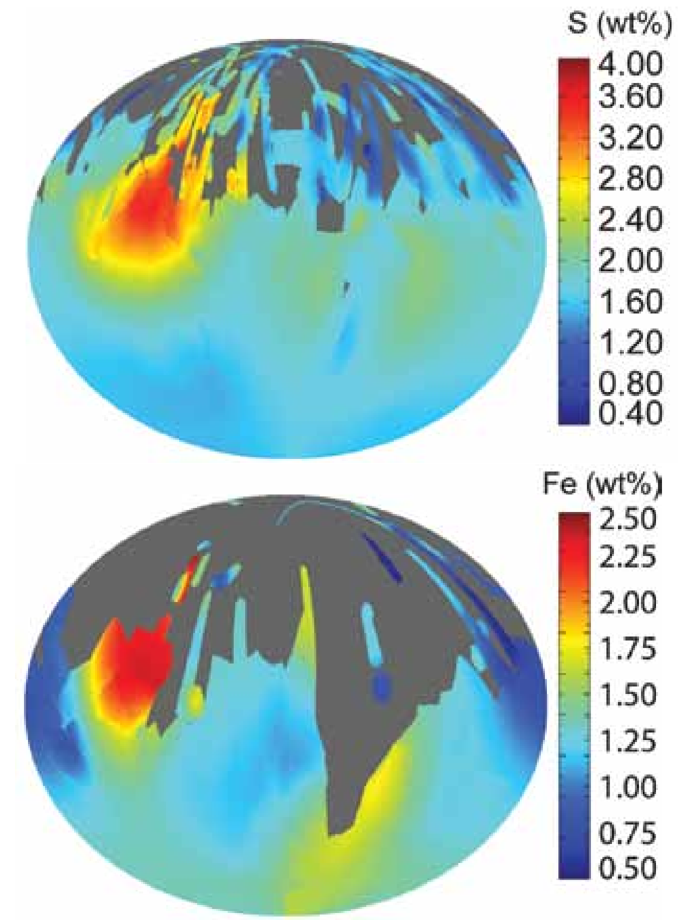
One of the large terranes discovered spans more than 5 million square kilometers (1.2 billion acres). It has the highest observed magnesium to silicon, sulfur to silicon, and calcium to silicon ratios, in addition to some of the lowest aluminum to silicon ratios on the planet's surface. The distinctive chemistry suggests mantle material was exposed during a very large and ancient impact event.

Using other measurements, the team also found that the smooth plains of the Caloris basin, Mercury's largest impact basin, have an elemental composition distinct from other volcanic plains. This suggests that Mercury's mantle has a strikingly diverse composition, with different volcanic plains representing parental magmas that were partial melts from chemically distinct portions of the mantle.



These maps show ratios of magnesium (*left*) and aluminum (*right*) to silicon across Mercury's surface. These maps, with maps of other elemental abundances, reveal the presence of distinct geochemical terranes.

Image courtesy NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution



Sulfur (*top*) is much higher, while iron (*bottom*) is much lower than the other terrestrial planet crusts (for example, Earth's crust is about 0.03% sulfur and 5% iron by weight). This composition suggests Mercury formed under much less oxidizing conditions and thus a different mix of starting materials than the other planets.

Image courtesy NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution

Genetics/Developmental Biology

Deciphering the Complexity of Cellular, Developmental, and Genetic Biology

A Natural “Band-Aid” for Wounds

Wound healing is short of miraculous. Traditionally, research has investigated how cell division replaces cells lost by injury. But what happens in organs that only have a limited capacity for cell division? Postdoctoral researcher Vicki Losick, in Allan Spradling’s lab, probed this question using the fruit fly *Drosophila melanogaster*. She studied healing in the adult fly’s abdominal epithelium, a thin layer of tissue below the fly’s exoskeleton. She found that wounds heal by cell growth instead of by cell division. In this case, the epithelial cells grew by polyploidization, a process by which cells can increase their DNA content resulting in two or more paired sets of chromosomes. By increasing a cell’s DNA content the cell can grow and support a larger cell volume. This is the first study demonstrating that polyploidy is essential to wound healing; Losick named this novel mechanism wound-induced polyploidy (WIP).

Vickie Losick found that wounds heal by cell growth instead of by cell division.

Fruit flies and mammals share many similar genes making flies ideal for studying biological processes. The fruit fly has been used to study repair mechanisms in embryos and larvae, but research in adults, which uses WIP, is in its infancy. Polyploid cells have been observed following injury to many organs in our body, but their role in wound repair has remained unknown. The fly could be a valuable proxy for understanding the basic molecular mechanisms that regulate WIP, enabling the healing capacity of polyploid cells to be exploited to improve human wound healing.

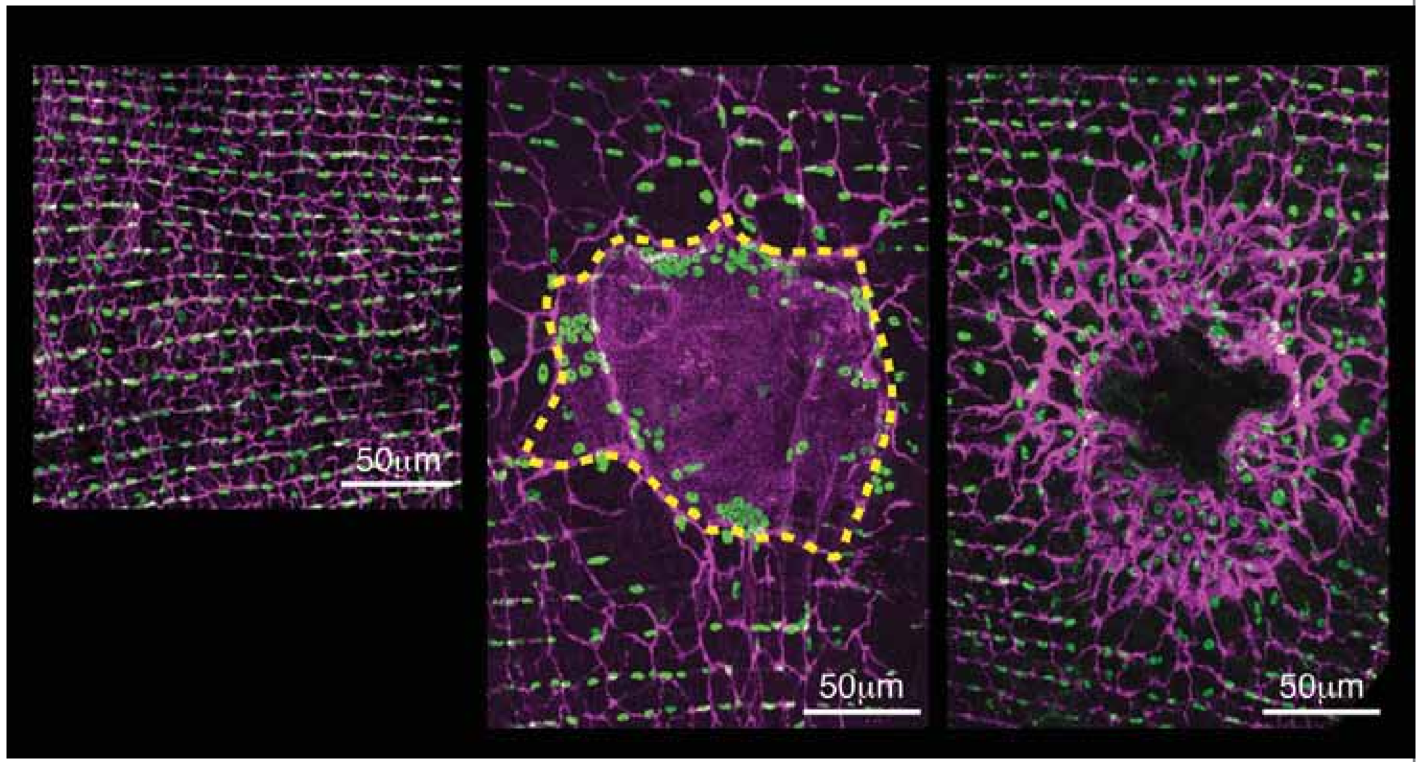
Losick has begun to uncover the underlying “signal transduction pathway” mechanism behind the healing activity of WIP. These pathways are molecular “bucket brigades,” in which molecules outside of a cell activate receptors at either the cell surface or inside the cell, which then trigger other molecules to respond to the stimulus. In this wound repair scenario, a pathway called Hippo, which controls the size of organs, is at work. Depending on the type of tissue, Hippo appears to sense cell loss and activate cell replacement either by WIP or by cell division. This new knowledge sets up the fascinating question of why cells would opt to grow big by WIP, instead of dividing, to heal a wound. Losick and Spradling speculate that polyploid cells provide advantages for the tissue, including stronger mechanical properties that help to stabilize the wound area.

For the first time, Vicki Losick in Allan Spradling’s lab demonstrated that so-called wound-induced polyploidy (WIP) is an essential part of our healing arsenal. WIP is a healing process in which a cell increases its DNA content and grows to support a larger cell volume, instead of healing by cell division.

Image courtesy Vicki Losick

Uninjured fruit fly tissue is shown below. The healed tissue made up of a giant polyploid cell (dashed outline) surrounded by other polyploid cells (bright green staining) is in the middle, and a mutant that blocks wound-induced polyploidy is at right. The fly epidermal nuclei are green, while cell-cell junctions are magenta.

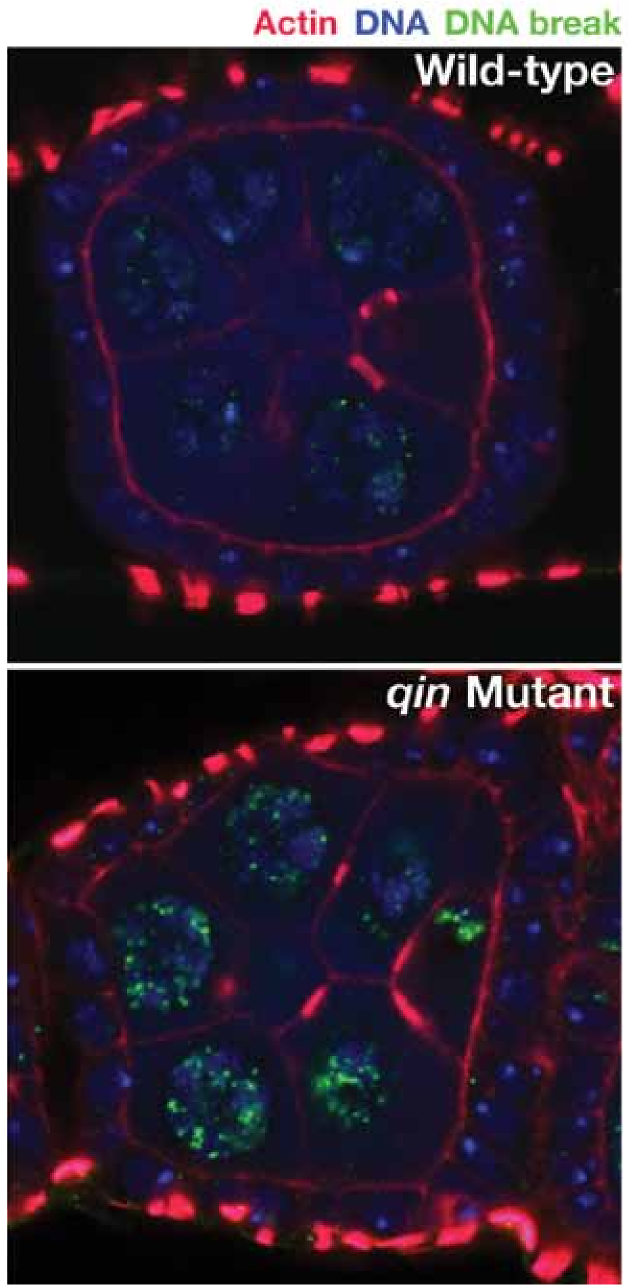
Image courtesy Vicki Losick



Finding Treasure in Junk

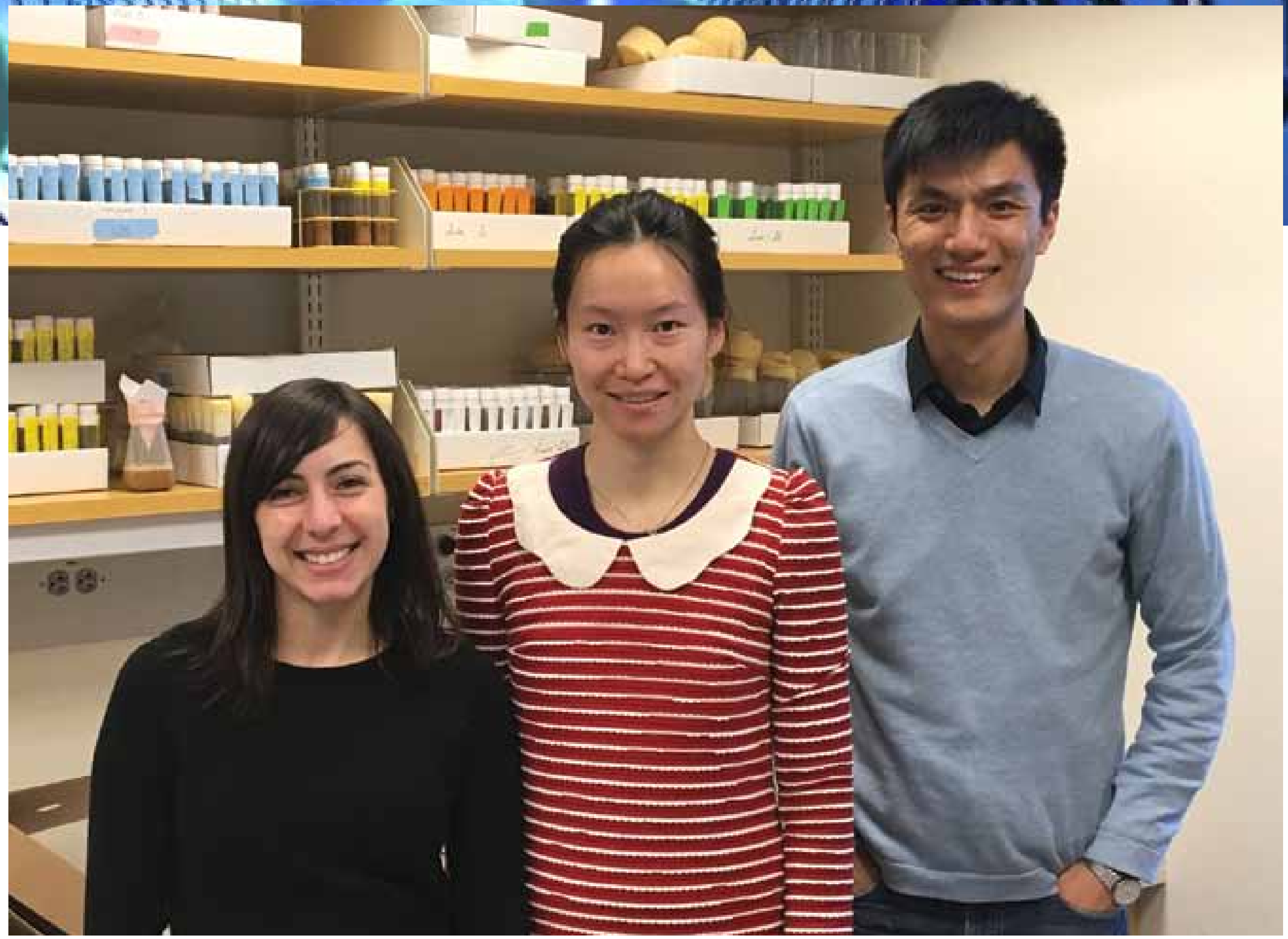
Most biologists study genes, which are only 1.5% of our genome. But since Zhao Zhang started graduate school, he has been fascinated by the most abundant elements in the rest of the genome, "junk" sequences called transposons. Also known as "jumping genes," these elements were first discovered by Carnegie scientist Barbara McClintock more than half a century ago. Making up at least 50% of our DNA, transposons can copy themselves within the genome much like viruses can. These genetic gypsies can wreak havoc on genome stability and integrity, often disabling genes and probably even trigging cancer. Zhang is developing new techniques, using the fruit fly *Drosophila melanogaster*, to study these most mysterious residents of our genome.

Failure to silence transposons in germ cells, precursors to egg and sperm cells, is the surest path to animal extinction. For this reason, animals have evolved a system in germ cells to put transposons under control. In this system, which is ancient in evolution and widespread across species, a specialized group of small RNA molecules—piRNAs—team up with certain proteins and create a "genomic immune system" to destroy products from transposons and shackle them in germ cells. With his colleagues, Zhang has discovered and named a gene, *qin*, found across species, which plays an essential role in this system. Mutating this gene leads to transposons jumping around in germ cells and animals becoming sterile.



(*Left*) Zhao Zhang discovered and named a gene, *qin*, that is involved in silencing "jumping genes." Each panel shows an egg chamber, the progenitor of mature oocyte, or egg. Mutating *qin* leads to transposons jumping around, DNA damage accumulation (green signal), and animal sterility.

Image courtesy Zhao Zhang



(*Above*) Members of the Zhang lab, from left to right are Madeline Cassani, Kun Dou, and Zhao Zhang.

Image courtesy Zhao Zhang

Compared with germ cells, we know surprisingly less about transposon activities in somatic cells—cells that produce other tissues. Do they jump at all? How do somatic cells control their activity? Does the activation of transposons cause any disease or lead to aging? If yes, can we use them as therapeutic targets?

Since transposons are present in our genome in multiple copies, sometimes thousands of copies, and current tools are not sensitive enough to capture the mobilization of individual elements, progress to address these questions is impeded. The Zhang lab is developing new tools to potentially capture single transposon jumping events with single-cell resolution and capable of probing insertion events in one cell from a large cell population. These new tools could bring us into a new era of transposon biology in somatic cells. They could help us understand ourselves at a different level and potentially provide another way to treat diseases, such as cancer.

Plant Science

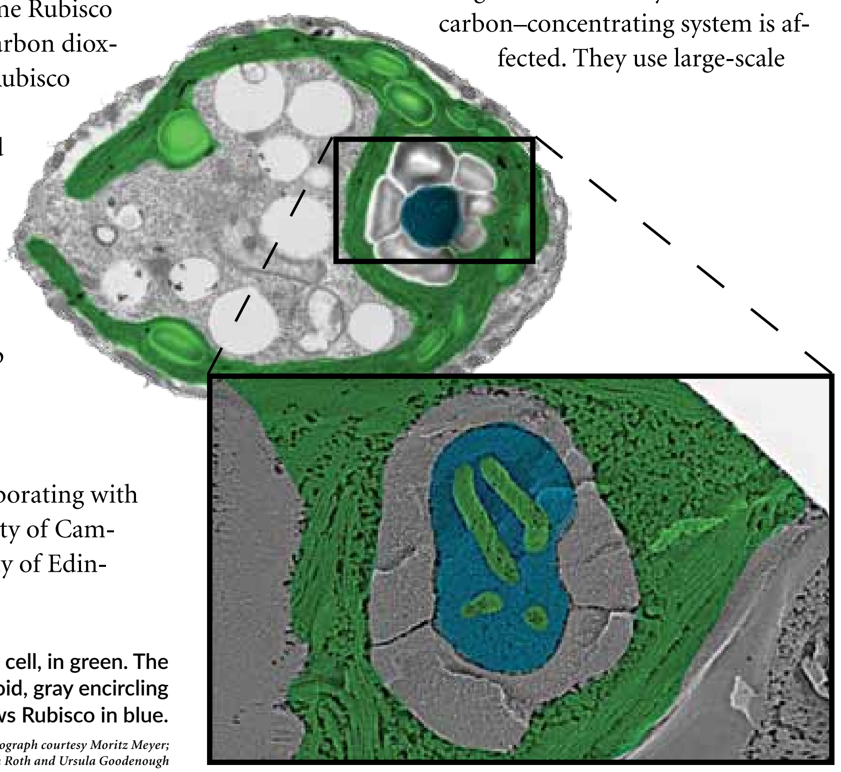
Characterizing the Genes of Plant Growth and Development

Turbocharging Photosynthesis

Martin Jonikas combines plant science with engineering to improve photosynthesis—the conversion of water, carbon dioxide, and sunlight into plant food and oxygen—to improve crop yields. When photosynthesis first evolved, the atmosphere contained much more carbon dioxide than it does today. The carbon-fixing enzyme Rubisco worked so well that it sucked most of the carbon dioxide out of the atmosphere. Today though, Rubisco is starving for carbon dioxide, limiting the growth rate of many crops. Green algae and so-called C4 plants like corn, however, overcome this limitation. They highly concentrate carbon dioxide before delivering it to Rubisco, via so-called carbon–concentrating mechanisms. The dream is to transfer this mechanism to crop plants, which could increase their yields by up to 60%.

To achieve this goal, the Jonikas lab is collaborating with the labs of Howard Griffiths at the University of Cambridge; Alistair McCormick at the University of Edinburgh; Mark Stitt and Michael Schroda at the Max Planck Institute of Molecular Plant Physiology; Ursula Goodenough at Washington University, St. Louis; and Stefan Geimer at the University of Bayreuth in a project called Combining Algal and Plant Photosynthesis (CAPP). The team's objectives are to identify the genes involved in the algal carbon–concentrating mechanism, to understand them, and finally to transfer this system to higher plants.

Of the 17,000 or so algal genes, five are known to be required for the carbon–concentrating mechanism. The team believes that at least a dozen more remain to be discovered. To identify the missing genes, the Jonikas lab eliminates genes individually to see if the carbon–concentrating system is affected. They use large-scale robotics to analyze hundreds of thousands of algal mutants for carbon–concentration defects.



The top image shows the chloroplast in an algal cell, in green. The chloroplast contains a feature called the pyrenoid, gray encircling blue. The close-up of the pyrenoid at bottom shows Rubisco in blue.

Top electron micrograph courtesy Moritz Meyer; bottom electron micrograph courtesy Robyn Roth and Ursula Goodenough

The Jonikas lab carbon-concentrating mechanism team, including collaborators from the United Kingdom, are shown from left to right: Martin Jonikas, Luke Mackinder, Vivian Chen, Nicky Atkinson (University of Edinburgh), Elizabeth Freeman, Alistair McCormick (University of Edinburgh), Howard Griffiths (Cambridge University), Leif Pallesen, Moritz Meyer (Cambridge University), and Alan Itakura.

Image courtesy Martin Jonikas

Algae and higher plants have chloroplasts, the organelle that conducts photosynthesis. However, the algal chloroplast has a special subcompartment not found in higher plants called a pyrenoid, which forms the heart of its carbon–concentrating mechanism. Algae put Rubisco in their pyrenoids and then pump a high concentration of carbon dioxide into Rubisco. Although little is known about how the pyrenoid is assembled, the Jonikas lab is discovering new genes that encode protein components of the subcompartment. With the Griffiths lab, they are determining the molecular role of each component, and an understanding of how the pyrenoid is assembled is beginning to emerge. The McCormick lab is now working to introduce the newly discovered components into higher plants.

Plant Science

Continued

Sleuthing Plant Growth Molecules

Plant cells have an interior scaffolding of proteins called a cytoskeleton that directs the construction of the cell walls and plant growth. Environmental signals, like light, and hormones prompt this scaffolding to reorganize. Yet the molecular mechanisms for this activity are not well understood. Carnegie's David Ehrhardt and team investigate this process in higher plants via real-time, live imaging. Their discoveries provide an important foundation for developing new crops and for understanding how conserved proteins work in both plants and animals.

The cytoskeleton includes protein arrays called microtubules. In rapidly growing cells, the microtubule network forms in a parallel array that wraps around the cell perpendicular to the main growth axis. Previously, Ehrhardt and colleagues showed how this array directs the delivery of cellulose synthase enzymes (cellulose is the main substance of cell walls) to the cell membrane and guides these enzymes as they synthesize the cell wall.

The team also looked at how the direction of a blue-light source influences a plant's growth, a phenomenon called phototropism. The responsible blue-light receptor protein, phototropin, was discovered by Carnegie's Winslow Briggs in the 1990s. Light perception through phototropin also drives a rapid rearrangement of the outer microtubule cytoskeleton in cells on the lit side of the plant stem.

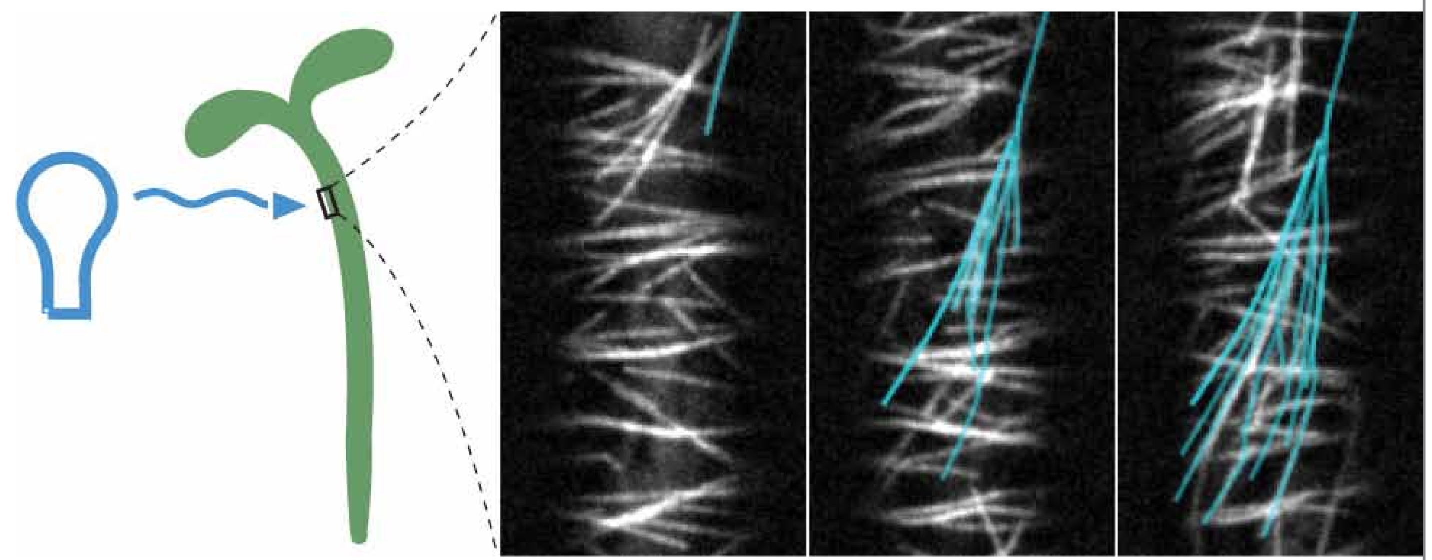
Imaging data and genetic experiments revealed that the reorientation of the cytoskeleton by blue-light perception is driven by a protein known as katanin, which severs microtubules. Previously, katanin was thought to be important for the disassembly of microtubule arrays. The Ehrhardt group found that katanin also has a creative role. It severs the microtubules, where they intersect each other, creating new ends that can regrow and then themselves be severed. This results in a rapid amplification of a new array oriented at about 90° to the original. This was the first time researchers demonstrated how blue light drives changes in cytoskeleton reorganization.

The researchers are now investigating the role of the cytoskeletal rearrangement in regulating phototrophic growth, the signaling mechanism between phototropin and katanin, and the role of other cytoskeletal regulatory mechanisms in reorientation. They have discovered two proteins that appear to be essential for rapid reorientation and stabilization of the new ends, work that they are preparing for publication.

...discoveries provide an important foundation for developing new crops and for understanding how conserved proteins work in both plants and animals.

Carnegie's Dave Ehrhardt has been a leader in developing new ways to visualize plant-cell imaging in real-time.

Image courtesy Robin Kempster



A microtubule array is visualized by live-cell imaging. The blue overlay shows a cascade of new microtubules generated from a single progenitor by sequential rounds of severing by the protein katanin and the growth of the severed ends. The new array is roughly orthogonal to the original.

Image courtesy Dave Ehrhardt

Global Ecology

Linking Ecosystem Processes with Large-Scale Impacts

Redefining Forest Biodiversity

Traditionally, the number and types of species per unit area defines biodiversity. But this way of looking at forests creates a huge gap between these species-based studies and the large-scale ecosystem and biosphere studies that tell us how our planet functions, including how water, carbon, nutrients, and other fundamental properties of the biosphere cycle and shift. To this end, Carnegie's Greg Asner and his Carnegie Airborne Observatory (CAO) team are using remote-sensing tools and tree-climbing fieldwork to get a much bigger picture of forest biodiversity—how a diversity of functions is arrayed across a landscape and how this relates to the more traditional species diversity.

In a series of papers published in 2014 and 2015, the CAO team learned how a range of forests and regions within forests differed from one another in terms of their contributions to the entire biosphere. They uncovered hidden mosaics of chemical variation across the topography of forest canopies in the Peruvian Amazon.

Thousands of tree and plant species are found in the Amazon. Each one synthesizes a complex portfolio of chemicals to accomplish a variety of functions that range from capturing sunlight to fighting off herbivores, to attracting pollinators and adapting to climate change.

These forests grow on an underlying geologic and hydrologic patchwork quilt, which also affects the diversity of chemical functions that forest plants undertake. Understanding the geographic variability of plant chemical activity is crucial to understanding the way an ecosystem functions on a large scale.

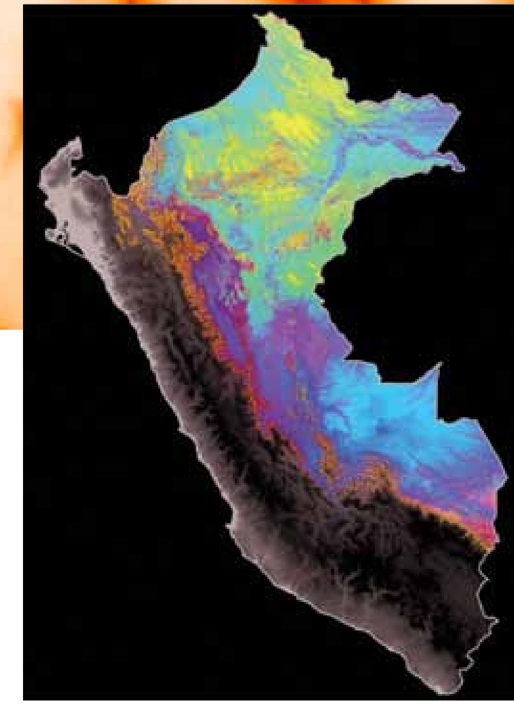
By improving our definition and understanding of biodiversity, Asner hopes that forest managers and policymakers will have a better understanding of how to protect a forest's portfolio of functions, not just its individual "head count" of trees and other plants. Understanding a forest's functional diversity is also crucial for assessing how climate change and human activities are altering these chemically unique ecosystems that have undergone millions of years of evolution and biogeographic construction to become the chemical mosaics that they are today.

Carnegie's Greg Asner works on the Carnegie Airborne Observatory.

Image courtesy Robin Kempster

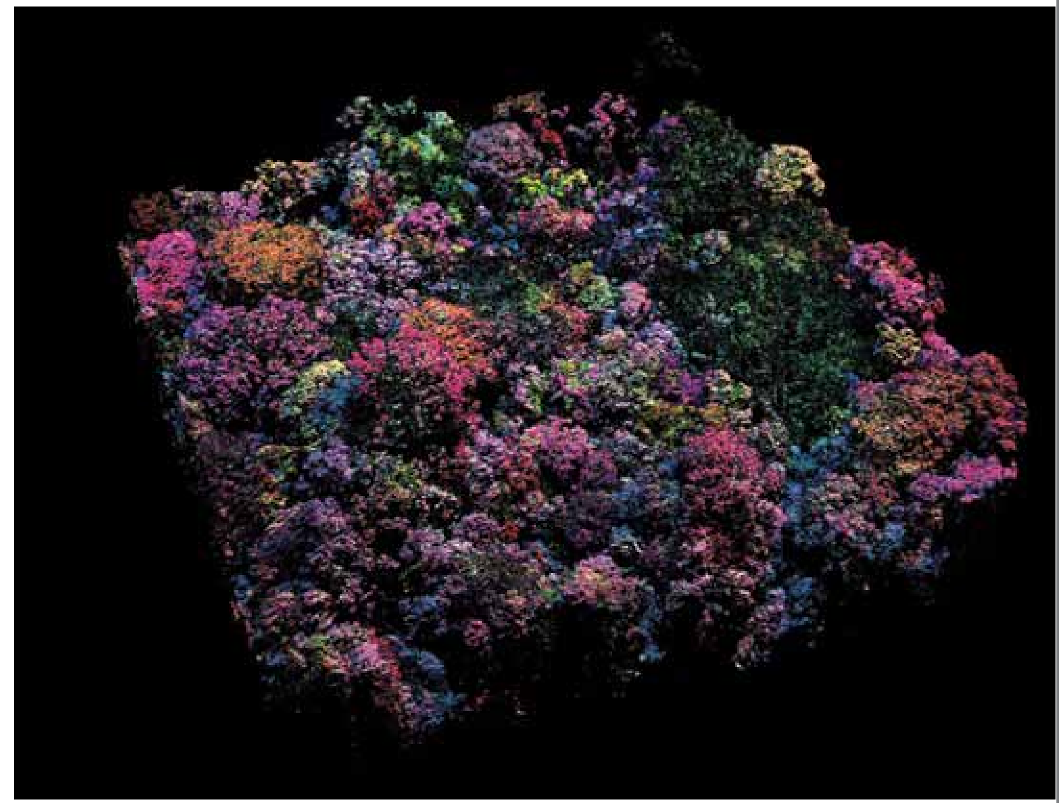
This image shows the chemical diversity of tree communities via different colors over 25,000 acres (10,000 hectares) of lowland Amazon rainforest.

Image courtesy Greg Asner



This huge swath of land shows the macroscale functional diversity of the Peruvian Andes and Amazon over 1.8 billion acres (72 million hectares).

Image courtesy Greg Asner

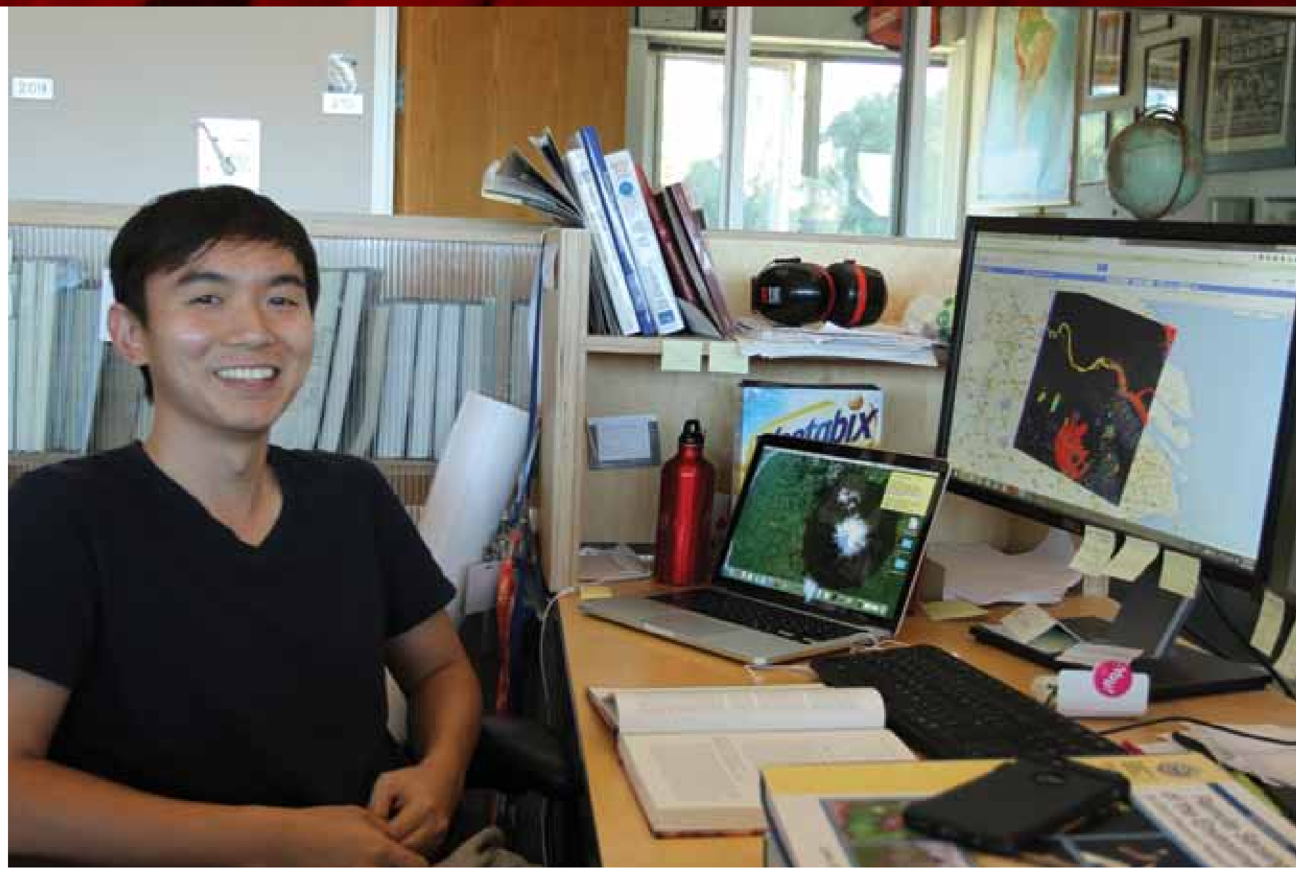


This image shows the 3-D functional diversity of one hectare (2.5 acres) of lowland Amazon rainforest.

Image courtesy Greg Asner

Global Ecology

Continued



Ph.D. student Jeff Ho works with Anna Michalak on the first-ever project of mapping algal blooms globally.

Image courtesy Ken Caldeira

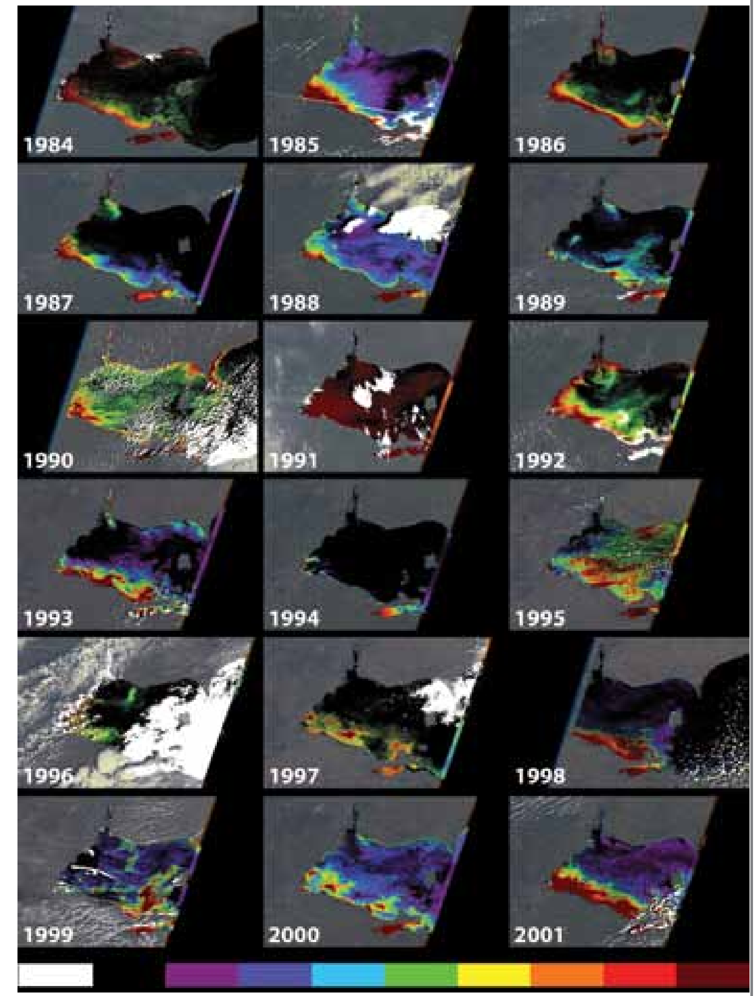
Tracking Algal Blooms Goes Global

Toxic algal blooms in freshwater lakes are becoming an epidemic. Nowhere is this more evident than in Toledo, Ohio, where toxic algae in Lake Erie caused a three-day tap water ban in the summer of 2014, leaving researchers seeking to better understand what causes these events and what can be done to stop them. Global data on blooms are lacking, with little known on their intensity, extent, and timing, except in a few well-researched lakes. This lack of information prevents researchers from determining how factors like global warming or nutrient loading are driving trends. Using remote sensing, Ph.D. student Jeff Ho and Anna Michalak are changing this. With Lake Erie as a test bed, the duo has vetted a new approach using historical LANDSAT data to track blooms. They are now partnering with Google Earth Engine to scale up the study to include the entire globe.

Rigorous testing of remote sensing algorithms was necessary before any global analysis could be attempted. As a first step, the researchers evaluated twelve LANDSAT algorithms for detecting phytoplankton using a novel approach that looked at how well each algorithm identified bloom occurrence, area, and timing. They selected the best performing algorithm, which is based on light signals in the near-infrared and shortwave infrared regions of the electromagnetic spectrum, and used it to look at a three-decade history of algal blooms in Lake Erie. Their research defied the prevailing view that there were no blooms from 1990 to 1992 and provided new information on how the current regime of large blooms began not abruptly as previously assumed, but gradually over several years. This revised history changes the way scientists look at Lake Erie's past, a clue to improving its future.

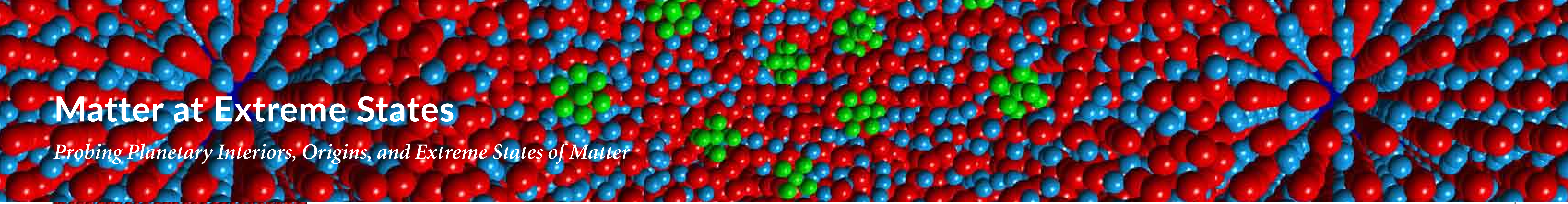
They are now partnering with
Google Earth Engine
to scale up...
to include the entire globe.

With their proof-of-concept in hand, Ho and Michalak won an award to map blooms globally from Google Earth Engine. Earth Engine aggregates 40 years of the world's satellite imagery for researchers to detect changes to Earth's surface. Ho and Michalak's goal is to generate the first long-term, self-consistent, and spatially precise data set on freshwater algal blooms globally. Along with collaborators worldwide, they plan to add new information via remote sensing on more than 167 lakes as they did for Lake Erie, something no other study has done before. The data will provide the foundation for mitigation efforts and for predicting when conditions are ideal for blooms to proliferate.



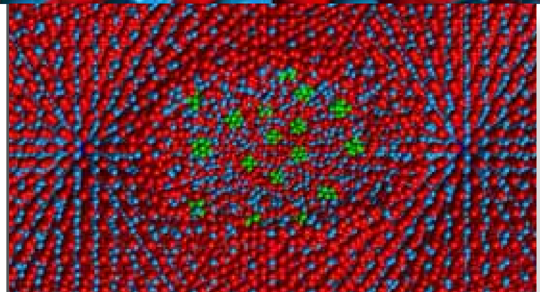
The LANDSAT data for Lake Erie shows modest and possibly declining blooms in 1984-1989, larger blooms starting in 1990, and new information that the 1995 and 1998 blooms were not as extensive as previously thought. The maps are the output of the algorithm the researchers selected, matched with *in situ* data. Open water is black, and red is the highest concentration of phytoplankton. Algorithm output is overlain on a true-color satellite image showing clouds and land.

Image courtesy Jeff Ho



Matter at Extreme States

Probing Planetary Interiors, Origins, and Extreme States of Matter



A Different Scenario for Deep CO_2 Cycling

Scientists can't venture to the deep Earth. So to understand earthquakes, volcanoes, plate tectonics, and the planet's evolution they mimic the Earth's high-pressure and high-temperature conditions in the lab. Recently, Dionysis Foustoukos and Bjørn Mysen took a new approach to deciphering how certain materials are deeply cycled. They found that carbonate minerals in the Earth's crust, where it slides under an adjacent tectonic plate (called subduction), may not recycle carbon dioxide (CO_2) for deep storage as effectively as previously thought. Instead, carbonate minerals may participate in melting processes that could contribute to the volcanic CO_2 emissions at subduction zones, where plates converge and chains of volcanoes called arcs arise.

Carbonate minerals contain the carbonate ion and a metal, such as iron or magnesium. As an oceanic crust sinks into the mantle, carbonates interact with other minerals, altering their chemistry. Understanding melt structure is important for deciphering volatile cycling of carbon (C), oxygen (O), hydrogen (H), nitrogen (N), and trace elements and metals.

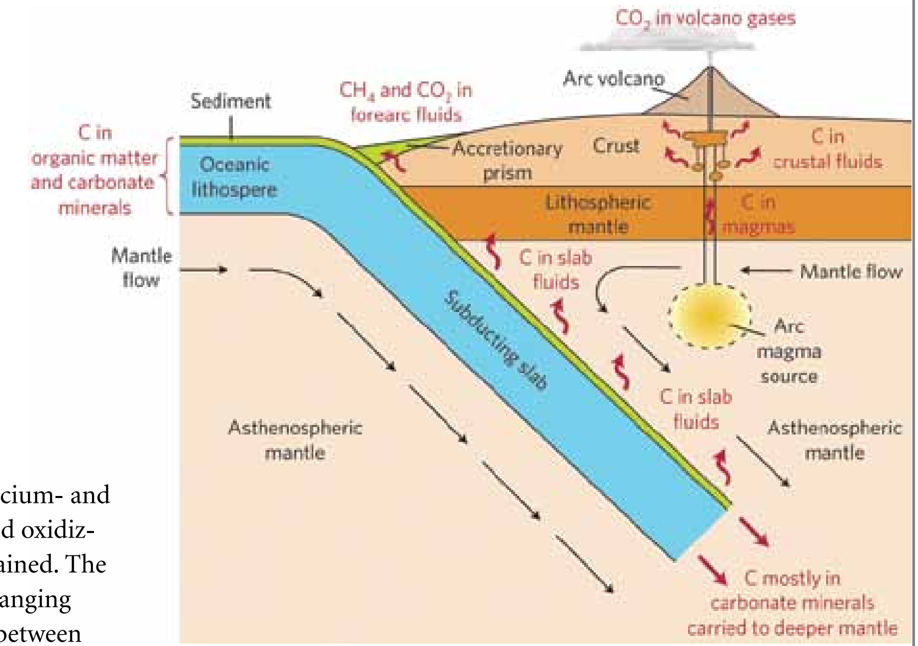
The duo used Raman vibrational spectroscopy to analyze squeezed samples in a diamond anvil cell and to observe the melting processes. In this method, laser light interacts with molecular vibrations from a sample as it is subjected to extreme conditions. As molecules change, a shift in light energy occurs, yielding specific chemical "fingerprints."

Bjørn Mysen (top left) and Dionysis Foustoukos (left) teamed up to study the cycling of carbon dioxide deep within the Earth.

Left image courtesy Dionysis Foustoukos; top left image courtesy Woods Hole Oceanographic Institute

This cutaway of the deep Earth shows what happens when the Earth's crust slides under the mantle in the process of subduction. During this process, carbon is carried down. It undergoes chemical reactions with increasing pressure and temperature and is then released back to the atmosphere at arc volcanoes.

Image courtesy Craig E. Manning, Nature Geoscience 7, 333–334, 2014, doi:10.1038/ngeo2152



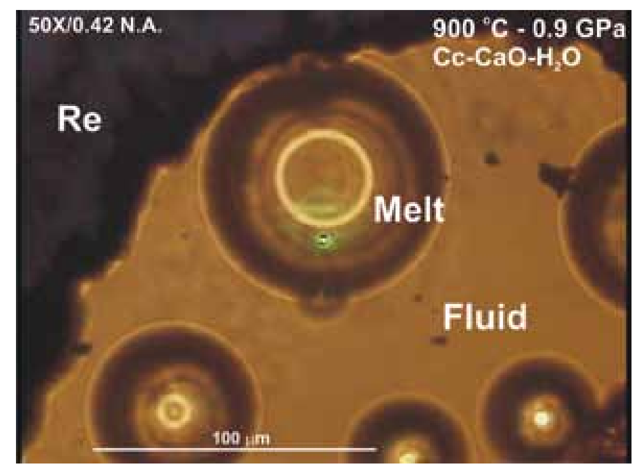
The investigators subjected water-saturated calcium- and magnesium-bearing carbonates to reducing and oxidizing conditions, in which electrons are lost or gained. The experiments were conducted at temperatures ranging from 750-2000°F (400-1100°C) and pressures between 4,400-28,000 times atmospheric pressure (442-2839 megapascals).

Melting occurred in the magnesium carbonate ($MgCO_3$)-magnesium oxide (MgO) system at 1550°F (850°C) and between 5,000 and 15,000 atmospheres. In the calcium carbonate ($CaCO_3$)-calcium oxide (CaO)-water (H_2O) system, melting occurred between 1100-1650°F (600-900°C) and pressures of 15,000-20,000 atmospheres (1.5-2 GPa). These pressures and temperatures correspond to about 50-60 miles (80-100 km) beneath the volcanic arc.

The results suggest that carbonate may not survive the transfer to sub-arc depths greater than 50 miles (80 km) and may start melting before the completion of dehydration at the slab-mantle interface, even at subduction zones with cold to intermediate temperatures. If correct, recycling of carbon into the mantle would be less efficient than previously thought, and a significant amount of CO_2 would likely be expelled via volcanoes.

Dionysis Foustoukos and Bjørn Mysen observed the melting processes of carbonate materials under conditions of the deep Earth. This image shows a sample under high-pressure, high-temperature conditions in a hydrothermal diamond anvil cell.

Image courtesy Dionysis Foustoukos



Matter at Extreme States

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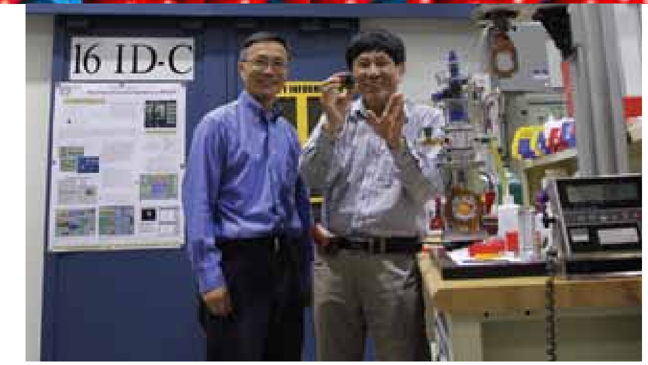


Dave Mao (right) has been a pioneer in the field of high-pressure research for over four decades. He continues to develop new instruments and methods that are expanding the field into new areas. He is shown with Gouyin Shen, the director of the High-Pressure Collaborative Access Team managed by Carnegie at the Advanced Photon Source, Argonne National Laboratory.

Image courtesy Dave Mao

Expanding High-Pressure Horizons

The science of matter under extreme pressures and temperatures was in its infancy when Ho-kwang (Dave) Mao starting breaking high-pressure records over four decades ago. He continues to develop instrumentation and methods to redefine this frontier, where chemistry morphs, electrons become erratic, magnetism warps, and new materials are born. Mao's legacy has expanded to China where he now leads the Center for High Pressure Science and Technology Advanced Research (HPSTAR).

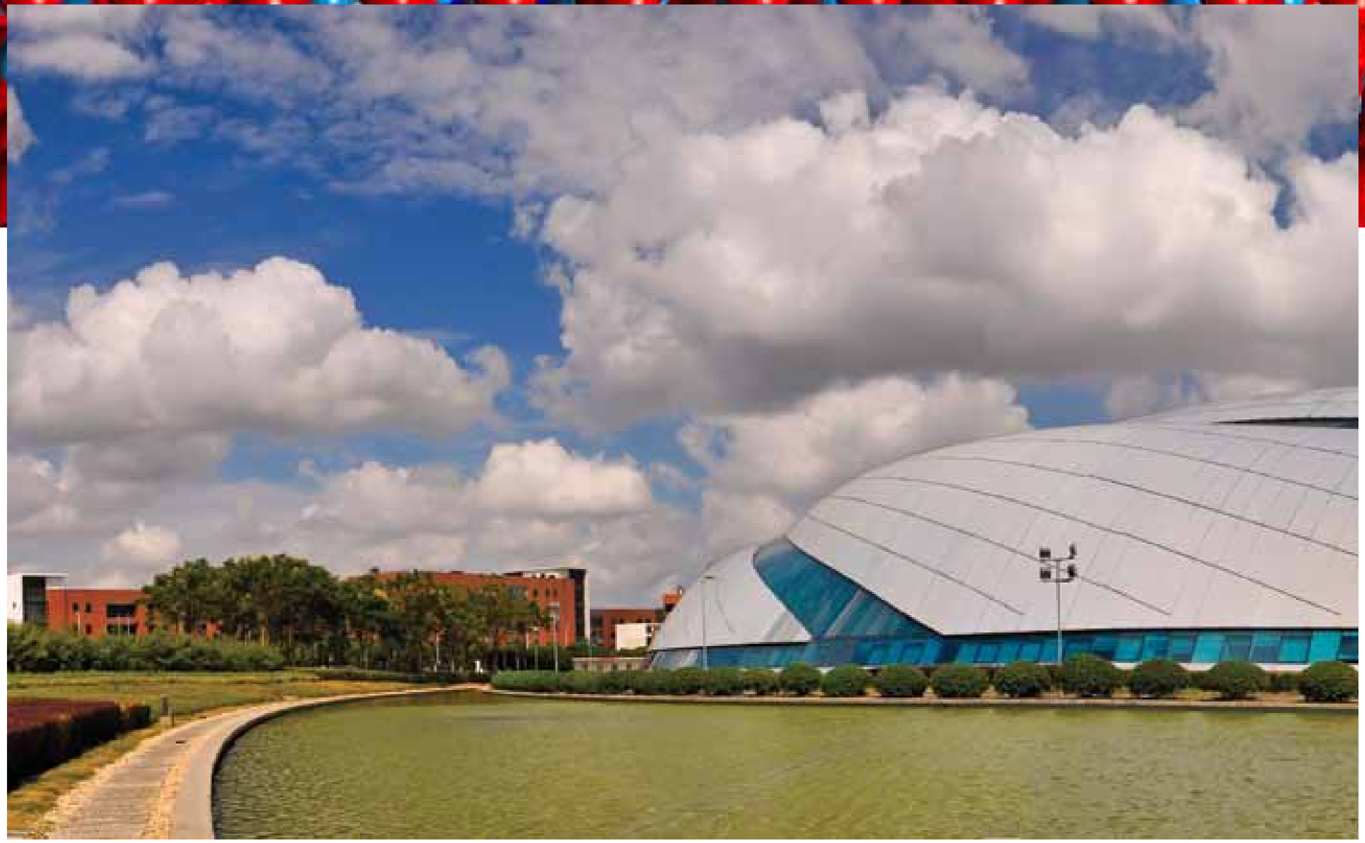
Mao's record-breaking work took off in 1975 when he and Peter Bell developed a diamond anvil cell, the workhorse of high-pressure research, which reached over 1,000,000 times atmospheric pressure. Today the field includes high-pressure chemistry, high-pressure crystallography, chemistry of the Earth's mantle and core, deep Earth geophysics, physics and chemistry of giant planetary interiors, and high-pressure materials science. The diamond anvil cell squeezes matter between two perfectly aligned single-crystal diamond tips. Matter is then measured with a wide range of probes including synchrotron X-rays; neutrons; and optical, electrical, and magnetic devices. But there are limits to the pressure diamond can withstand without breaking.

Recently, other researchers developed diamonds made up of many smaller crystals that achieve pressures of over 6 million atmospheres (640 GPa). Pressures in the Earth's core, for comparison, are about 3.5 million atmospheres (350 GPa), and the cores of gas giants range from 5.8 to 47.4 million atmospheres (580 to 4740 GPa).

Mao is adapting the diamond anvil cell to reach pressures beyond these current limits by shaping the pressure-bearing tips of the anvil with a focused ion beam.

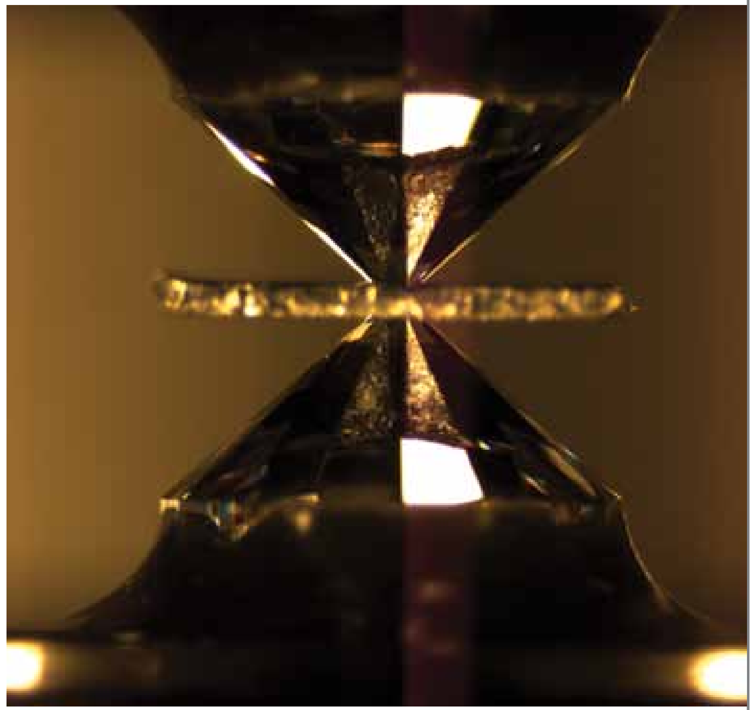
In another push to unleash the full potential of this field, the Chinese government established HPSTAR, led by Mao since September 2012, to become a leader in this area. It is modeled after Carnegie by supporting independence, advanced facilities, and a collaborative research environment. HPSTAR scientists explore the high-pressure worlds of physics, chemistry, technology, photon science, nanoscience, functional materials, energy science, superhard materials, and Earth and planetary interiors.

Mao is adapting the diamond anvil cell to reach pressures beyond these current limits...



In addition to his role as senior scientist at Carnegie, Dave Mao is also the director of the Center for High Pressure Science and Technology Advanced Research (HPSTAR), shown here (above) in Shanghai, China.

Image courtesy Yue Meng



The workhorse of high-pressure research is the diamond anvil cell (right). Two perfectly aligned diamond tips squeeze samples to high pressures. Scientists use a variety of probes to measure what happens to the material as it undergoes chemical and physical changes.

Image courtesy Steve Jacobson

HPSTAR was first established in Shanghai, followed by laboratories in Changchun and Beijing. The center is projected to grow to 90 faculty members and 600 others including graduate students, postdoctoral fellows, visiting scientists, engineers, and administrative personnel in the next decade.

2014-2015 YEAR BOOK

Financial Profile

for the year ending June 30, 2015 (unaudited)

Reader's Note: *In this section, we present summary financial information that is unaudited. Each year the Carnegie Institution, through the Audit committee of its Board of Trustees, engages an independent auditor to express an opinion about the financial statements and the financial position of the institution. The complete audited financial statements are made available on the institution's website at www.CarnegieScience.edu.*

The Carnegie Institution for Science completed fiscal year 2015 in sound financial condition due to the positive returns (+7.3%) of the diversified investments within its endowment; a disciplined spending policy that balances today's needs with the long-term requirements of the institution and the interests of future scientists; and the continued support of organizations and individuals who recognize the value of basic science.

The primary source of support for the institution's activities continues to be its endowment. This reliance on institutional funding provides an important degree of independence in the research activities of the institution's scientists.

As of June 30, 2015, the endowment was valued at $991 million. Over the period 2001-2015, average annual increases in endowment contributions to the budget were 5.0%. Carnegie closely controls expenses in order to ensure the continuation of a healthy scientific enterprise.

For a number of years, under the direction of the Investment committee of the board, Carnegie's endowment has been allocated among a broad spectrum of asset classes including: equities (stocks), absolute return investments, real estate partnerships, private equity, natural resources partnerships, and fixed-income instruments (bonds). The goal of this diversified approach is to generate attractive overall performance and minimize the volatility that would exist in a less diversified portfolio.

The Investment committee of the board regularly examines the asset allocation of the endowment and readjusts the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody. The following chart shows the allocation of the institution's endowment among asset classes as of June 30, 2015.

Asset Class	Target	Actual
Common Stock	37.5%	41.7%
Alternative Assets	55.0%	45.4%
Fixed Income and Cash	7.5%	12.9%

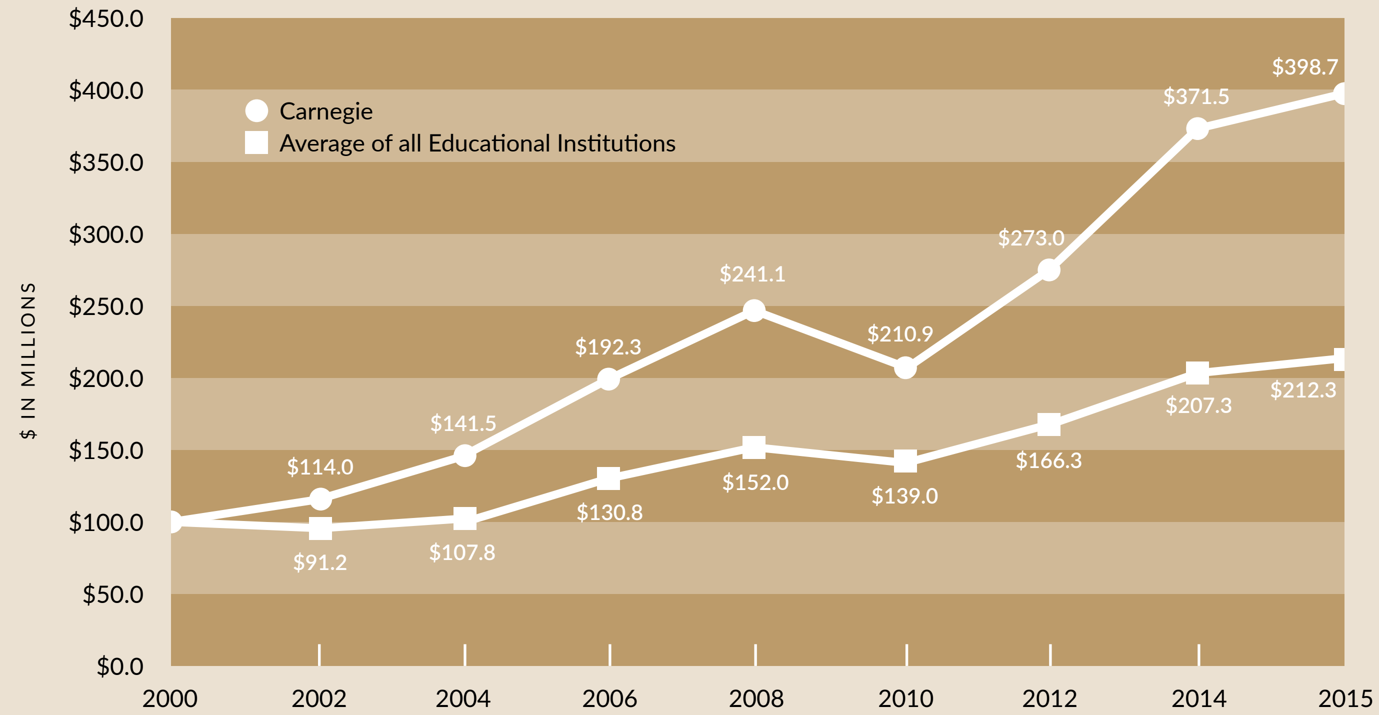
Carnegie's investment goals are to provide high levels of current support to the Institution and to maintain the long-term spending power of its endowment. The success of Carnegie's investment strategy is illustrated in the following figure that compares, for a hypothetical investment of $100 million, Carnegie's investment returns with the average returns for all educational institutions for the last fifteen years.

Carnegie has pursued a long-term policy of controlling its spending rate, bringing the budgeted rate down in a gradual fashion from 6+ % in 1992 to 5% today. Carnegie employs what is known as a 70/30 hybrid spending rule. That is, the amount available from the endowment in any year is made up of 70% of the previous year's budget, adjusted for inflation, and 30% of the most recently completed year-end endowment value, multiplied by the spending rate of 5% and adjusted for inflation and debt. This method reduces volatility from year-to-year. The following figure depicts actual spending as a percentage of ending market value for the last 23 years.

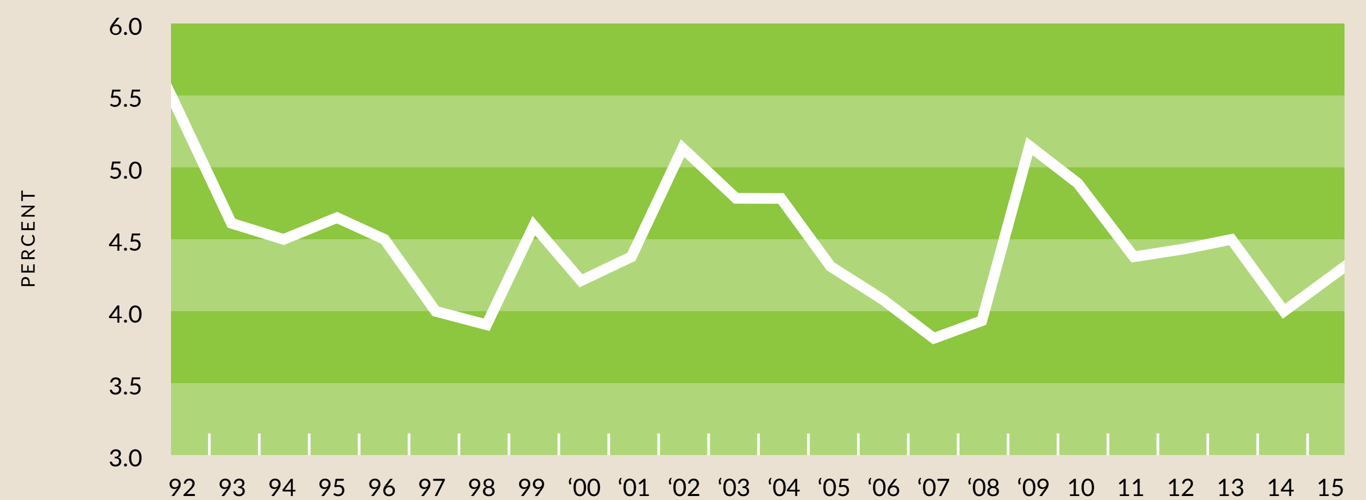
In fiscal year 2015, Carnegie benefitted from continuing federal support. Carnegie received $22.8 million in new federal grants in 2015. This is a testament to the high quality of Carnegie scientists and their ability to compete successfully for federal funds in this period of fiscal restraint.

Carnegie also benefits from generous support from foundations and individuals. Funding from foundations has grown from an average of about $3 million/year in the period from 2000 to 2004 to $11 million in 2015. Within Carnegie's endowment, there are a number of "funds" that provide support either in a general way or targeted to a specific purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of $10 million. Mr. Carnegie later made additional gifts totaling another $12 million during his lifetime. This tradition of generous support for Carnegie's scientific mission has continued throughout our history and a list of donors in fiscal year 2015 appears in an earlier section of this year book. In addition, Carnegie receives important private grants for specific research purposes, including support from the Howard Hughes Medical Institute for researchers at the Department of Embryology.

Illustration of $100 Million Investment — Carnegie Returns vs. Average Returns for All Educational Institutions (2000-2015)



Endowment Spending as a Percent of Ending Endowment Value*



* Includes debt financing.

Statements of Financial Position (Unaudited)

June 30, 2015, and 2014

	2015	2014
Assets		
Current assets:		
Cash and cash equivalents	$ 16,120,426	$ 4,093,370
Accrued investment income	73,772	11,988
Contributions receivable	7,077,572	11,280,393
Accounts receivable and other assets	8,966,680	9,188,678
Bond proceeds held by Trustee	49,434,798	49,414,262
Total current assets	81,673,248	73,988,691
Noncurrent assets:		
Investments	983,996,467	984,182,412
Property and equipment, net	137,996,467	140,153,915
Long term deferred assets	21,992,598	17,598,331
Total noncurrent assets	$1,143,605,259	$ 1,141,934,658
Total assets	$1,225,278,507	$ 1,215,923,349
Liabilities and Net Assets		
Accounts payable and accrued expenses	$ 10,145,114	$ 11,234,976
Deferred revenues	27,431,440	28,055,413
Bonds payable	115,057,854	115,064,362
Accrued postretirement benefits	25,923,865	23,558,628
Total liabilities	$ 178,558,273	$ 177,913,379
Net assets		
Unrestricted	$ 310,287,147	$ 306,552,812
Temporarily restricted	681,328,124	676,403,916
Permanently restricted	55,104,963	55,053,242
Total net assets	$1,046,720,234	$ 1,038,009,970
Total liabilities and net assets	$1,225,278,507	$ 1,215,923,349

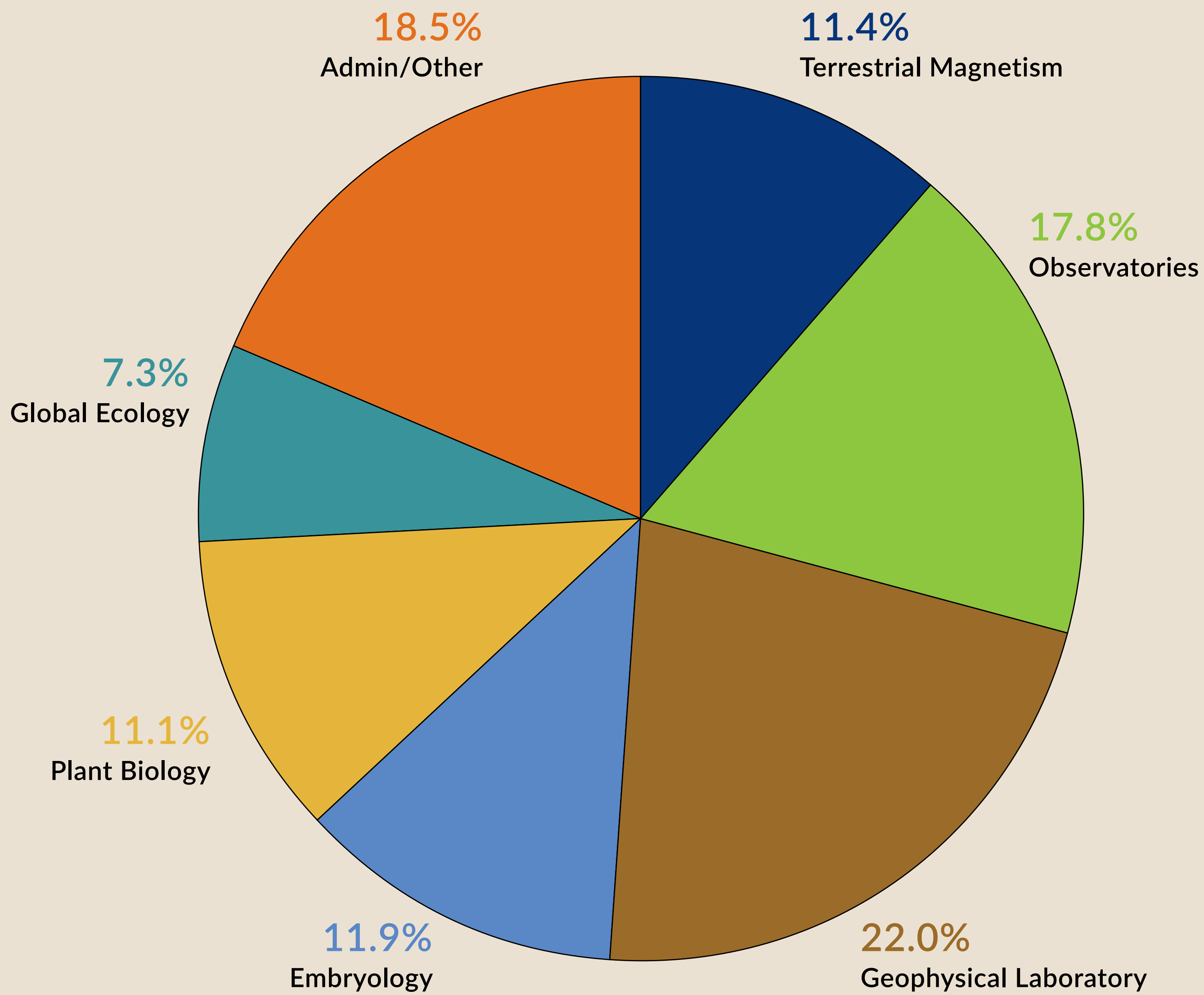
Statements of Activities[1] (Unaudited)

Periods ended June 30, 2015, and 2014

	2015	2014
Revenue and support:		
Grants and contracts	$ 37,738,760	$ 35,708,599
Contributions, gifts	10,610,849	10,438,061
Other income	6,213,102	2,645,768
Net external revenue	$ 54,562,711	$ 48,792,428
Investment income and unrealized gains (losses)	$ 58,482,948	$ 170,662,287
Total revenues, gains, other support	$ 113,045,659	$ 219,454,715
Program and supporting services:		
Terrestrial Magnetism	$ 11,769,589	$ 12,858,902
Observatories	18,318,574	19,181,747
Geophysical Laboratory	22,714,496	20,079,387
Embryology	12,269,662	11,778,108
Plant Biology	11,402,502	11,119,082
Global Ecology	7,563,559	8,432,635
Other programs	1,046,000	1,250,486
Administration and general expenses	17,975,643	14,205,604
Total expenses	$ 103,060,025	$ 98,905,951
Change in net assets before pension related changes	$ 9,985,634	$ 120,548,764
Pension related changes	(1,275,370)	(2,440,448)
Net assets at the beginning of the period	$ 1,038,009,970	$ 919,901,654
Net assets at the end of the period	$1,046,720,234	$1,038,009,970

[1] Includes restricted, temporarily restricted, and permanently restricted revenues, gains, and other support.

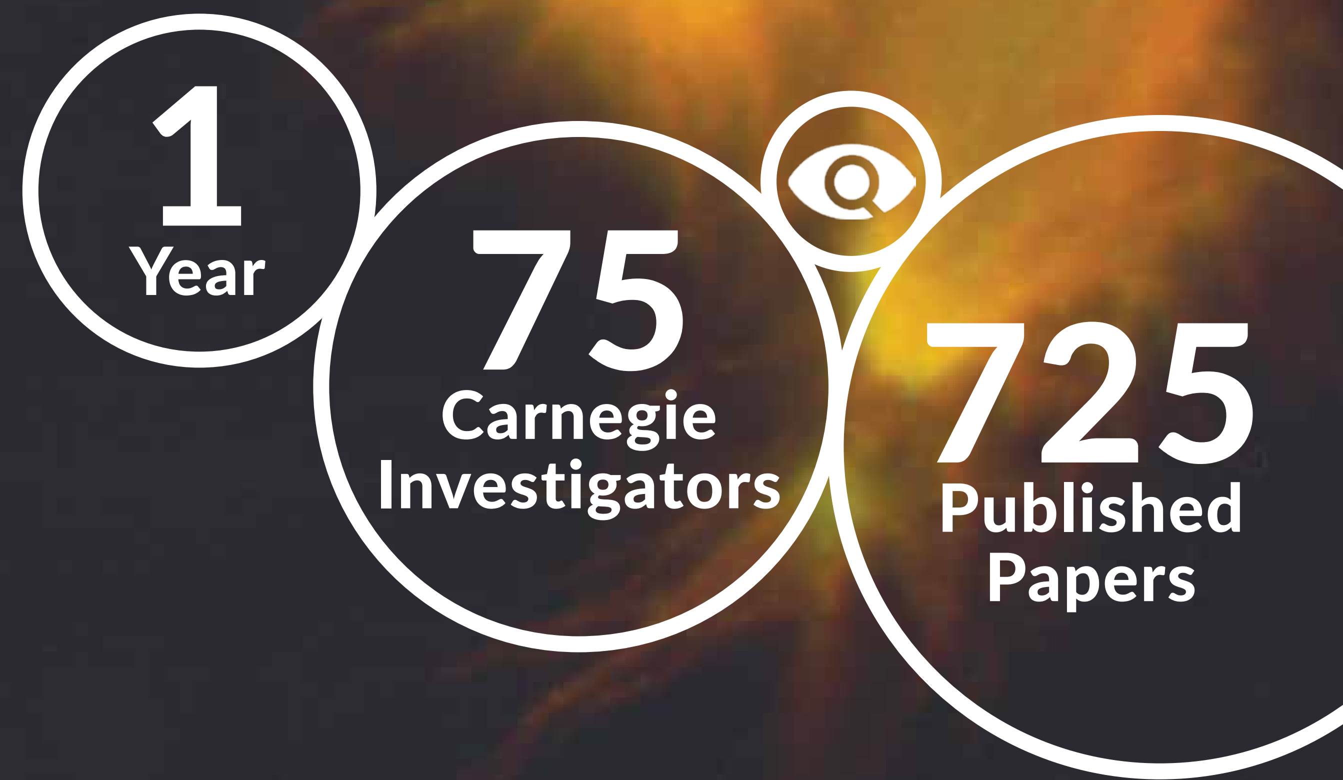
2015 Expenses by Department ($103.1 Million)



Small Size, Big Impact

Some 75 Carnegie investigators, with postdoctoral fellows and other colleagues, machinists, business administrators, facilities staff, and more contributed to some 725 papers published in the most prestigious scientific journals during the last year. Many discoveries were widely covered by the media and had extensive social media reach.

For a full listing of personnel and publications see
http:/CarnegieScience.edu/yearbooks



Carnegie Investigators
IN THE NEWS

"One thing Asner discovered…was that 1 billion tons of carbon… embedded in Peruvian forests is at imminent risk of being emitted…"

GREG ASNER IN NEWSWEEK

"…two critical parts of ovulation that seem to be the same for both flies and mice."

ALLAN SPRADLING AND JIANJUN SUN IN PHYS.ORG

"Basically the storms that we should've had in California ended up whacking New England."

CHRIS FIELD IN THE WEATHER CHANNEL

"The quasar, the brightest ever detected in the early universe, was found..."

YURI BELETSKY IN THE GUARDIAN

"…the supernova explosion that caused the birth of our sun may have also given rise to our solar system's rotation, allowing for the formation of the planets…"

ALAN BOSS IN THE DAILY MAIL

"Panel urges research on geoengineering as a tool against climate change."

KEN CALDEIRA IN THE NEW YORK TIMES

"Mysterious radio burst captured in real-time for first time ever."

MANSI KASLIWAL IN THE HUFFINGTON POST

"A new imaging tool… allows researchers to study the dynamic of growth of root systems in soil and uncover the molecular signaling pathways…"

JOSÉ DINNENY IN AGROFESSIONAL WEEKLY

"Some minerals may have helped early organisms emerge."

ROBERT HAZEN IN WIRED

"…findings answer long-held questions about embryonic plant nutrition and have major potential importance for improving crop yield."

WOLF FROMMER IN SCIENCE WORLD REPORT

"A missing link to the 1930s theory of metals proves that thermal convection drives the Earth's magnetic field."

RONALD COHEN IN THE INTERNATIONAL BUSINESS TIMES

« THE DEPARTMENT OF EMBRYOLOGY

Genetics/Developmental Biology

Front row (left to right): Jennifer Brubaker, Bill Kupiec, Tom McDonaugh, Erik Duboué, Mary Best, Shusheng Wang, Gennadiy Klimachev. Second row: Ebrahim Darvish, Pedram Nozari, Wilber Ramos, Mahmud Siddiqi, Marla Tharp, Allan Spradling, Patricia Cammon, Jack Pinder, Andrew Rock, Meredith Wilson. Third row: Joseph Gall, Jean-Michael Chanchu, Carmen Tull, Jessica Otis, Jen Anderson, Zehra Nizami, Lakshmi Gorrepati, Zhao Zhang, Gaelle Talhaourne, Sibiao Yue, Lin Lin. Fourth row: Chen-Ming Fan, Dolly Chin, Steven Farber, Sveta Deryusheva, Ming-Chia Lee, Jui-Ko Chang, Ethan Greenblatt, Kun Dou, Chenhui Wang, Ona Martin, Jiabiao Hu. Fifth row: Rebecca Obniski, Vicki Losick, Robert Levis, Dianne Williams, Carol Davenport, Allison Pinder, Lynne Hugendubler, Madeline Cassani, Lydia Li, Tyler Harvey. Sixth row: Mike Sepanski, Kevin Smolenski, Valeriya Gaysinskaya, Simen Vlasov, Fred Tan, Yuejia Huang, Marnie Halpern, Jay Thierer, Safia Malki, Zheng-An Wu. Seventh row: Sarina Raman, Ankita Das, Jung-Hwa Choi, Alex Bortvin, Michelle Macurak, Connie Jewell, Micah Webster, Christoph Lepper, Samantha Satchell.

Carnegie Investigators

Research Staff Members

- ALEX BORTVIN
- DONALD D. BROWN, Director Emeritus
- CHEN-MING FAN
- STEVEN A. FARBER
- JOSEPH G. GALL
- MARNIE E. HALPERN
- ALLAN C. SPRADLING, Director
- YIXIAN ZHENG

Staff Associates

- CHRISTOPH LEPPER
- ZHAO ZHANG [1]

[1] From November 2014

Carnegie Investigators

Staff Scientists

- GEORGE D. CODY, Acting Director
- RONALD E. COHEN
- YINGWEI FEI
- ALEXANDER F. GONCHAROV
- ROBERT M. HAZEN
- RUSSELL J. HEMLEY
- T. NEIL IRVINE, Emeritus
- HO-KWANG MAO
- BJØRN O. MYSEN
- DOUGLAS RUMBLE III
- ANAT SHAHAR
- ANDREW STEELE
- TIMOTHY A. STROBEL
- VIKTOR V. STRUZHKIN

THE GEOPHYSICAL LABORATORY »

Matter at Extreme States, Earth/Planetary Science

Front row (left to right): Colin Fauguerolles (visitor), Maceo Bacote, Ivan Naumov, Sushmita Patwardhan (visitor), Kadek Hemawan, Xiaowei Sun, Raja Vadapoo, Yangzheng Lin, Zhixue Du, Christian Hansen (visitor), Todd Zapata, Minqiang Hou, Takaki Muramatsu, Huiyang Gou, Xiaomiao Zhao, Hanyu Liu, Jianjun Ying, Gefei Qian, Qianqian Wang. Second row: Akihito Tonosaki, Aida Farough (visitor), Dyanne Furtado, Michelle Scholtes, Hiroyuki Takenaka, Anat Shahar, Corliss Kin I Sio, Michelle Hoon-Starr, Pablo Esparza, Agnes Mao, Jinfu Shu, Doug Rumble, Andrew Needham, Adelio Contreras, Kevin Shu, Duck Young Kim, Yufei Meng, Helen Venzon, Christiana Bockisch (visitor), Chao Liu, Abhisek Basu, Irena Mamajanov, Jihua Hao, Nick Holtgrewe, Thomas Shiell. Back row: Matthew Ward, Tomasz Jaron, Seth Wagner, Sergey Lobanov, Zack Geballe, Tim Strobel, Andrea Mangum, Michael Meyer, Trong Nguyen, Emma Bullock, George Cody, Gary Bors, John Armstrong, Andrew Steele, Gabor Szilagyi, Victor Lugo, Daniel Hummer, Merri Wolf, Michael Ackerson, Shi Liu, Joseph Lai, Dionysis Foustoukos, Ho-kwang (Dave) Mao, Quintin Miller, Viktor Struzhkin, Shaun Hardy, Hitoshi Gomi, Haidong Zhang, Venkata Bhadram.

« THE DEPARTMENT OF GLOBAL ECOLOGY

Global Ecology

From left to right: Angelica Vasquez, Anna Michalak, Bill Hayes, Nina Randazzo, Garret Huntress, Jovan Tadic, Mae Qiu, Katie Mach, Rebecca Albright, Shavon Jones-Mansaw, Eva Sinha, Mike Mastrandrea, Xiaochun Zhang, Soheil Shayegh, Tuai Williams, Jeff Ho, Ken Caldeira, Michele Dalponte (visitor), Kai Zhu, Emily Francis, Dave Knapp, Grayson Badgley, Dave Marvin, Yuanyuan Fang, Dana Chadwick, Jennifer Scerri, Evana Lee, Andrew Davies, Phil Brodrick, Nick Vaughn, Ismael Villa, Maria Slade, Yoichi Shiga, Mary Whelan, Kelly McManus, Ari Kornfeld, Hulya Aksoy, Robin Martin, Dahlia Wist, Greg Asner, Joe Berry, Min Chen, Scot Miller, Kathi Bump, Naoia Williams, Ali Kasper, Theo van de Sande, Patrick Freeman, Chris Field, Chris Balzotti, Todd Tobeck.

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- GREGORY ASNER
- JOSEPH A. BERRY
- KENNETH CALDEIRA
- CHRISTOPHER B. FIELD, Director
- ANNA MICHALAK

Carnegie Investigators

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- REBECCA BERNSTEIN
- ALAN DRESSLER
- WENDY FREEDMAN, Director [1]
- LUIS HO
- JUNA KOLLMEIER
- PATRICK MCCARTHY
- ANDREW MCWILLIAM
- JOHN MULCHAEY, Director [2]
- AUGUSTUS OEMLER, JR., Director Emeritus
- ERIC PERSSON
- GEORGE PRESTON, Director Emeritus
- MICHAEL RAUCH
- FRANÇOIS SCHWEIZER [3]
- STEPHEN SHECTMAN
- JOSHUA SIMON
- IAN THOMPSON
- RAY WEYMANN, Director Emeritus

Research Associates
- DAN KELSON, Staff Associate
- BARRY MADORE, Senior Research Associate

Technical Staff Members
- ALAN UOMOTO, Magellan Technical Manager

[1] To August 31, 2014
[2] From April 27, 2015, formerly Staff Member and Associate Director for Academic Affairs
[3] To August 31, 2014, now Staff Member Emeritus

THE OBSERVATORIES »

Astronomy

The staff of Carnegie Observatories is standing on the life-sized drawing of the upcoming Giant Magellan Telescope. First row (left to right): Josh Simon, Juna Kollmeier, Jeffrey Crane, Charlie Hull, Christoph Birk, Mansi Kasliwal, Alan Uomoto, Rachel Beaton, Jennifer van Saders, Ben Shappee, Victoria Scowcroft, Stephanie Tonnensen, Janet Colucci, Tatsu Monkman,* Mackenzie Vignout,*Erika Carlson,*Andrew Benson, John Mulchaey, Jorge Estrada. Back row: Greg Ortiz, Jerson Castillo, Robert Storts, Tom Meneghini (Mt. Wislon Institute),*Vincent Kowal, Christopher Burns, Mark Seibert, Irina Strelnik, Daniel Kelson, Sung-Ri Sok, Yu Lu, Shannon Patel, Andrew Wetzel*, Jeffrey Rich, Ian Thompson, George Preston, François Schweizer, Luis Ochoa, Christopher Cannella,*Andrew McWilliam, Yu Xuan Hong,*Anthony Piro, Viraj Pandya,* Earl Harris, Barry Madore, David Vartanyan,*Beverly Fink, Laura Sturch, Tyson Hare, Becky Lynn, Scott Rubel.
*Visitors/students

« THE DEPARTMENT OF PLANT BIOLOGY

Plant Science

First row (left to right): Theo van de Sande. Second row: Ronald Halim, Devaki Bhaya, Wei-Feng, unnamed intern, Sue Rhee, Vivian Chen, Jiaying Zhu, Nina Ivanova, Xiaobo Li, Chris Chen, Xuelian Yang. Third row: Lina Duan, José Sebastian, Jebasingh Selvanayagam, Liz Freeman, Kathryn Barton, Matt Evans, Kathi Bump, XiaoQing Qu, Wolf Frommer, Wenqiang Yang. Fourth row: Yuval Kaye, Cheng-Hsun Ho, Jessica Foret, Vanessa Castro-Rodríguez, Aurelie Grimault, Evana Lee, Veder Garcia, Martin Jonikas, Dahlia Wist, Robert Jinkerson, Ted Raab, Shixuan Li. Fifth row: Sarah Fajon, Shai Saroussi, Lily Cheung, Heike Lindner, Joëlle Sasse-Schläpfer, Masayoshi Nakamura, Pascal Schlapfer, Susan Cortinas, Naoia Williams, Josep Vilarasa-Blasi, Tingting Xiang, José Dinneny, Alan Itakura, Ismael Villa. Sixth row: Friedrich Fauser, Tyler Wittkopp, Diane Chermk, Taylor Marie, Yan Gong, Matt Prior, Joon-Seob Eom, Man Ao, Peifen Zhang, Ankit Walia, M.C. Yee, Heather Cartwright, Wei-Chuan Kao, Thomas Hartwig, Arthur Grossman. Seventh row: Haojie Jin, Anchal Chandra, Adam Iodine, Sophia Xu, Hong Bo Ye, Jitze Jelmer Lindeboom, Antony Chettoor, Jacob Robertson, Neil Robbins, Michelle Davison, Eunkyoo Oh, Flavia Bossi, Jennifer Scerri, I Lin, Rick Kim, Bi Yang, Sunita Patil, Michael Banf, Chuan Wang, Chanho Park. Last row: Tuai Williams, Maria Slade.

Carnegie Investigators

Research Staff Members

M. KATHRYN BARTON
WINSLOW R. BRIGGS, Director Emeritus
JOSÉ DINNENY
DAVID EHRHARDT
WOLF B. FROMMER, Director
ARTHUR R. GROSSMAN
SEUNG Y. RHEE
ZHI-YONG WANG

Adjunct Staff

DEVAKI BHAYA
MATTHEW EVANS

Young Investigator

MARTIN JONIKAS

Senior Investigator

THEODORE RAAB

Carnegie Investigators

Research Staff Members

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ALAN P. BOSS
PAUL BUTLER
RICHARD W. CARLSON, Director[1]
JOHN E. CHAMBERS
MATTHEW J. FOUCH[2]
JOHN A. GRAHAM, Emeritus
ERIK H. HAURI
ALAN T. LINDE[3]
LARRY R. NITTLER
DIANA C. ROMAN
SCOTT S. SHEPPARD
STEVEN B. SHIREY
SEAN C. SOLOMON, Director Emeritus[4]
FOUAD TERA, Emeritus
LARA WAGNER[5]
ALYCIA J. WEINBERGER

Senior Fellow

I. SELWYN SACKS

THE DEPARTMENT OF TERRESTRIAL MAGNETISM »

Earth/Planetary Science and Astronomy

Front row (left to right): Christopher Thissen, Conel Alexander, Sergio Dieterich, Erika Nesvold, Winston (Lara's dog), Lara Wagner, Mary Horan, M.A. O'Donnell. Second row: Myriam Telus, Timothy Rodigas, Rita Parai, Jessica Donaldson, Nan Liu, Amanda Lough, Janice Dunlap, Erik Hauri, Robin Dienel (behind her is Tyler Bartholomew), Wan Kim, Pablo Esparza, Johanna Teske. Third row: Adelio Contreras, Maceo Bacote, Alycia Weinberger, Ben Pandit, Jianhua Wang, Diana Roman, Brian Schleigh, Shaun Hardy, Peter Driscoll, Jaqueline Faherty. Last row: Quintin Miller, Alan Boss, Gary Bors, Steven Shirey, Kevin Johnson, Merri Wolf, John Chambers, Brad Foley, Steven Golden, Richard Carlson, Steve Richardson.

[1] From November 4, 2014
[2] To July 31, 2014
[3] Retired on July 31, 2015
[4] On Leave of Absence
[5] From August 18, 2014

A Gift for the Future

One of the most effective ways of supporting the work of the Carnegie Institution is to include the institution in your estate plans. By doing so, you can support cutting-edge, independent scientific research well into the future.

Estate gifts are a tangible demonstration of your dedication to the Carnegie Institution and can potentially generate significant tax savings for your estate. These gifts can be directed to support fellowships, chairs, specific research projects, or other programs and can be additions to the endowment. For additional information, please contact the Office of Advancement at 202.387.6400.

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www.CarnegieScience.edu/support

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